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MOTION DYNAMICS OF A COUPLED LIGHTER AND SEALIFT SHIP IN SEAWAYS: A PARAMETRIC STUDY

by

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The joint services are presently working together to develop inter-operable components that will perform effectively as an integrated cargo transfer system compatible with sealift operations conducted in heavy seas through sea state 3. Providing rough water components is not in itself a sufficient condition for guaranteeing sea state 3 performance, however. Even as major hardware systems with sea state 3 maturity are fielded, other critical ship and shore interface links remain sea-state limited. The Naval Facilities Engineering Service Center is exploring new technologies that will enable U.S. military watercraft to exchange cargo with sealift ships during heavy seas.

In a typical operation of Joint Logistics Over the Shore (JLOTS), cargo is offloaded from a large container vessel onto a smaller watercraft, such as the Amphibious Cargo Beaching (ACB) lighter, using an auxiliary crane ship (T-ACS) to make the required lifts. For the docking model of an ACB lighter coupled directly to a T-ACS during sea state 3, this report presents analytical results for motions and forces. The method of analysis selected requires the application of two successive computer codes: a hydrodynamic model that determines such basic vessel characteristics as added mass, damping and wave excitation, and a motion response model that uses output from the hydrodynamic model to calculate absolute and relative motions, and coupling forces. The stated objective is to predict typical motion responses and coupling forces so that a baseline for design requirements can be developed in support of a concept being incubated by the Government.

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EXECUTIVE SUMMARY

The joint services are presently working together to develop inter-operable components that will perform effectively as an integrated cargo transfer system compatible with sealift operations conducted in heavy seas through sea state 3. Providing rough water components is not in itself a sufficient condition for guaranteeing sea state 3 performance, however. Even as major hardware systems with sea state 3 maturity are fielded, other critical ship and shore interface links remain sea-state limited. The Naval Facilities Engineering Service Center is exploring new technologies that will enable U.S. military watercraft to exchange cargo with sealift ships during heavy seas.

In a typical operation of Joint Logistics Over the Shore (JLOTS), cargo is offloaded from a large container vessel onto a smaller watercraft, such as the Amphibious Cargo Beaching (ACB) lighter, using an auxiliary crane ship (T-ACS) to make the required lifts. For the docking model of an ACB lighter coupled directly to a T-ACS during sea state 3, this report presents analytical results for motions and forces. The method of analysis selected requires the application of two successive computer codes: a hydrodynamic model that determines such basic vessel characteristics as added mass, damping and wave excitation, and a motion response model that uses output from the hydrodynamic model to calculate absolute and relative motions, and coupling forces. The stated objective is to predict typical motion responses and coupling forces so that a baseline for design requirements can be developed in support of a concept being incubated by the Government.

The matrix of input variables addressing rough water conditions includes a number of wave directions, wave heights, wave periods, sea state conditions, spring stiffness coefficients, and dashpot damping values. All simulations are executed on the basis of an assumed 10-foot separation between lighter and ship, and "deep water" conditions of at least 300 feet. Results are presented in the format of charts containing modeled response information on absolute motion, relative motion, and coupling force. It is concluded that the hydrodynamic response of the ACB lighter in a sea state 3 environment is very pronounced, whereas the T-ACS is stable and subdued. The lighter is excited most significantly by wave periods of 4 to 6 seconds, a range that coincides with the frequency band of greatest energy in sea state 3. In addition, the motional response of the lighter is altered significantly by the presence of the larger ship, whereas the behavior of the T-ACS is little influenced by interaction with the lighter. The ship therefore provides an effective means of sheltering. An ACB lighter stationed on the weather side may experience motions as much as 60 percent greater than if stationed on the leeward side. In conclusion, the effects and counter-effects of mechanical coupling significantly affect the overall dynamics of motion. Predictions from the parametric study show that resonance is likely and may be a significant factor in designing structural members. And larger, stiffer components do not necessarily mitigate the relative motions experienced between vessels. It is therefore critical to design an interface structure with fender and mooring systems that properly tune both stiffness and damping so that system resonance frequencies differ from peak frequencies of the incident wave energy.

CONTENTS

INTRODUCTION

The Amphibious Systems Division at the Naval Facilities Engineering Service Center (NFESC) has been funded by the Office of Naval Research (ONR) to explore new technologies that will enable U.S. military lighters, known collectively as watercraft, to exchange cargo with sealift ships during heavy seas. According to published Joint Logistics Over the Shore (JLOTS) requirements, "To achieve a complete sea state 3 (ss3) capability, all LOTS systems must inter-operate in 5-foot waves. The Services are presently working together to develop major systems – such as cranes, lighters, causeways, discharge platforms, and related support equipment – that will perform effectively together as a total system in ss3." Providing rough water components is not in itself a sufficient condition for guaranteeing sea state 3 performance, however. Even as major hardware systems with sea state 3 maturity are fielded, other critical ship and shore interface links remain sea-state limited. The primary objective of this effort is to help ensure the continuity of JLOTS throughput requirements by providing a means for receiving and discharging ship-to-shore cargo safely and efficiently, even during periods of rough water. To initiate the effort, a hydrodynamic analysis was conducted that quantifies the motions and forces required in establishing an engineering baseline for concept development. The results of the study are presented and discussed in this report.

BACKGROUND

During a recent JLOTS exercise, several days of potential throughput were sacrificed because lighters were unable to work after sea state 3 conditions were ushered in by a sudden storm. This experience is similar to JLOTS exercises of the past when rough waters exceeding sea state 2 conditions forced watercraft to retreat to shelter (Refs 1 and 2).

A Heavy Weather (e.g., sea state 3 and above) JLOTS Options Study conducted in 1996 addressed all weather issues relating to sustained JLOTS performance, including the following factors identified by Vaughters and Mardiros (Ref 3):

1. The status and operational capability of each JLOTS component
2. The identification of weak links limiting rough water operation
3. The description and characterization of potential solutions
4. The potential cost and effectiveness of potential solutions
5. The recommended drafting of a JLOTS total system developmental plan

The study allocated each significant JLOTS component to one of three categories: ship operations, lighter operations, or beach/surf zone operations. Two of the significant weak-link deficiencies defined as lighter ship-to-shore functions were identified as: (1) the docking interface between a watercraft and sealift vessel in active seas, and (2) the docking interface between a watercraft and pier structure in active seas.

Successfully transferring cargo between a watercraft and ship or pier requires that the lighter maintain position at its station, relative to the ship or pier, by either mooring to the ship

or pier via a protective interface structure, or by otherwise holding a fixed standoff relative to ship or pier. The concept of fixed standoff implies the application of methods such as dynamic positioning and intuitive control, where typically the lighter is held in check by the power of its own thrusters. An onboard computer rapidly samples and processes environmental and directional data, sending a steady stream of corrective instructions to the propulsion system. In the more conventional docking sequence, the lighter is moored against the ship or pier for cargo transfer. In even the calm water scenario, it is mandatory that the docking face between vessels be protected by an effective fender system that buffers against collision damage. To provide protection and stability in heavy seas, it is almost imperative that the passive docking arrangement be augmented by some means of damping, reducing or otherwise synchronizing the relative motions and forces between watercraft and ship or pier.

In a typical JLOTS scenario, cargo is offloaded from sealift vessels onto smaller watercraft which then shuttle the goods to a near-shore pier or beach facility. The auxiliary crane ship (T-ACS) shown in Figure 1 is a specialized sealift vessel outfitted with heavy deck cranes for lifting containers from a containership and placing them onto watercraft, such as the Amphibious Cargo Beaching (ACB) lighter. The ACB lighter is a 120-foot long by 24-foot wide pontoon barge that has been identified as a candidate replacement to the aging fleet of Navy-lightered (NL) barges, now used in LOTS and JLOTS operations. In a typical action scenario, the ACB lighter docks against the T-ACS as cargo is removed from the containership and loaded onto the smaller vessel. The analytical results presented in this report are limited to the motions and forces resulting from a conventional cargo-transfer model that couples an ACB lighter to the auxiliary crane ship ***Keystone State*** in heavy seas. The method of analysis requires the application of two successive computer codes: a hydrodynamic model that determines such basic vessel characteristics as added mass, damping and wave excitation, and a motion response model that uses output from the hydrodynamic model to calculate absolute and relative motions and coupling forces. The analyses that were conducted do not address cargo-transfer sequences that rely on methods of dynamic positioning or intuitive control. A separate hydrodynamic study will be required to model the absolute and relative motions, and to calculate the onboard power requirements, resulting from a lighter that is maintained on station during sea state 3 conditions by the performance of its own thrusters.

OBJECTIVE

The objective of the hydrodynamic analysis is to predict typical motion response and associated coupling forces that would likely be encountered in a sea state 3 operation. The analytical results will be used to define the baseline design requirements needed to proceed with development of a working concept for rough water operations. In current JLOTS practice, as a lighter is positioned for mooring against a sealift ship such as a T-ACS, both vessels are buffered against collision damage by their protective fendering systems. Existing fender systems continue protection as coupled vessels bob side-by-side because JLOTS cargo-transfer operations are currently limited to the relative calm of sea state 2 conditions. As heavier seas develop, it becomes increasingly more difficult to bring vessels together safely without mishap. Fenders alone are not capable of protecting against severe rolling motions induced by heavy seas. The passive protection provided can quickly succumb to the chaos and frenzy of vibrant seas. As lighter and ship welter helter-skelter in conditions that degrade into slam dancing, the ability of

conventional fender and mooring configurations to cushion impact forces and absorb snap-loading tensions is very seriously challenged. A novel standoff system capable of absorbing sudden impacts and dampening excessive relative motions is required.

Government Concept

The Government is developing a conceptual interface structure that offers potential promise as a means for safely docking in rough water. To be useful to the joint services, the system concept must accommodate the spectrum of Army and Navy lighters operating within the JLOTS arena.

The fundamental engineering characteristics of the government concept are depicted conceptually in Figure 2. The primary hardware component is a removable frame structure that can be mounted to the side of a cargo ship on the high seas. The frame assembly features a number of critical functions. First, the frame provides a safe standoff distance between ship and watercraft to prevent damage to either hull by direct impact during the approach and cargo transfer operations. Second, the frame affords vertical latitude for moving protective fender assemblies either up or down, providing an effective means of resisting separation forces while also enabling lighters of disparate deck height to be equally well accommodated. Third, the frame and/or frame-to-deck mounting interface are equipped with a damping mechanism to absorb high impact forces and reduce the effects of sudden snap loading. Fourth, the frame is equipped with adjustable components that may be used to tune the elastic and damping characteristics required during a particular docking operation, mitigating the coupling motions and loads. Thus, this novel conceptual scheme incorporates some of the critical features required of a safe sea state 3 docking operation: (1) adequate vessel separation, (2) adjustable fender protection, (3) damped forces, (4) reduced relative motions, and (5) removable hardware.

SCOPE

In order to establish a baseline of required design criteria, a hydrodynamic analysis was conducted under BAA contract to Ocean Dynamics of Calabasas, California, to quantify the coupled motions and forces. The scope of analysis under this effort called for the execution of a hydrodynamic analysis to predict the coupled behavior of an ACB lighter moored to the T-ACS ***Keystone State*** under various sea conditions, using a generic mass-spring dashpot model to simulate the interface structure. This report presents the government perception and interpretation of the analysis results provided by Ocean Dynamics. The ship particulars for the ACB lighter and T-ACS vessel are contained in Table 1. Figure 3 presents the body plan for the ***Keystone State***, and Figure 4 depicts the coordinate system and simplified model chosen to emulate the docking arrangement.

The matrix of input variables addressing rough water conditions includes a number of wave directions, wave heights, wave periods, sea state conditions, spring stiffness coefficients, and dashpot damping values. All simulations have been executed on the basis of an assumed 10-foot separation between lighter and ship, and "deep water" conditions of at least 300 feet. The results are presented tables and charts containing modeled response information on absolute motion, relative motion, and coupling force.

Table 1. Ship Particulars for T-ACS and ACB Lighter

	Keystone State	*Lighter*
DWT	13,600	
LOA	633 ft	120 ft
Beam	76 ft	24 ft
Draft	31.7 ft	4 ft
LCG	322.7 ft	60 ft
KCG	21 ft	4 ft
Displacement	6.40E7 lb 29,091 mt	7.37E5 lb 335 mt
Radius of gyration		
Transverse	27.4 ft	8.64 ft
Longitudinal	158.3 ft	34.2 ft
Moment of inertia		
I_{xx}	4.8E10 lb-ft^2	5.5E7 lb-ft^2
$I_{yy}=I_{zz}$	1.6E12 lb-ft^2	8.62E8 lb-ft^2

Regular Wave

A total of 40 computer runs were executed for the regular wave condition. For that simulation, a wave height of 5 feet was chosen. Eight wave directions (0, 45, 90, 135, 180, 225, 270, and 315 degrees) were selected, according to the convention shown in Figure 5, and five wave periods (4, 6, 8, 10, and 12 seconds) were assumed.

Random Wave

A total of 16 computer runs were executed for the random wave condition. For that simulation, two sea states, ss3 and ss4, were assumed in conjunction with the same eight wave directions listed for the regular wave. Sea state 3 was defined using the Piersson-Moscowitz spectrum as a 5.0-foot significant wave height and 6.2-second peak period; sea state 4 was defined as a 7.5-foot significant wave height and 7.6-second peak period.

Spring Stiffness and Dashpot Resistance

A total of 135 computer runs were executed to determine the sensitivity of hydrodynamic responses to changes in the magnitude of spring stiffness and dashpot damping. This series of runs assumed a regular wave of height 5 feet, three wave directions (head, beam, and quartering seas), five wave periods (4, 6, 8, 10, and 12 seconds), three values of spring stiffness (10, 40, and 70 kips/ft), and three values of dashpot resistance (4, 7, and 10 percent of critical damping). The

values of spring stiffness selected were equivalent to typical sizes and performance characteristics for Bridgestone foam fenders, which are rated between 17.4 and 62.6 kips/ft.

ANALYSIS

The dynamic interactions of multiple vessels positioned in close proximity are evaluated simultaneously as a coupled system. Because the vessels under consideration are significantly heavier and appreciably more rigid than the coupling structure being modeled, the dynamic response of combined system is simulated by means of a lumped mass-spring dashpot model. In the model, each vessel is treated as a rigid element (or a node) represented by a point mass located at its center of gravity. Coupled elements are connected with mass-less elastic springs and dashpots. The motion of the vessels induced by ambient waves under the constraints of coupling structures is addressed using a mathematical model that accommodates Newton's second law. For the sake of mathematical convenience, a random seaway is further decomposed into a series of harmonic waves, which in turn excite vessels into harmonic motions at the corresponding frequency. Applying these assumptions, the mathematical representation of the motional response of the vessel system is reduced to a simple governing equation, presented in terms of complex amplitudes of forcing functions and motion displacements as follows:

$$[M + M_a]\, X + [B+B_v+B_c]\, X + [K+K_s]\, X = F \qquad (1)$$

where M = 12x12 mass matrix of coupled lighter and ship

M_a = 12x12 added mass matrix

B = 12x12 wave damping matrix

B_v = viscous damping

B_c = fender damping

K = hydrostatic restoring force matrix (12x12)

K_s = stiffness matrix (12x12) of dashpot spring

F = wave exciting force vector (12x1)

In this equation, the matrix $[M_a]$ contains the added mass coefficients and matrix [B] contains the hydrodynamic damping coefficients, both representing ambient water resistances to vessel motions. The matrix [F] contains terms for wave excitation. All these force characteristics are frequency dependent and must be determined in a preliminary procedure, using a fluid-structure-coupling model based on potential theory, before Equation 1 can be solved numerically. The calculations are made using the computer code MORHAL2, one in a suite of MORA programs developed by C.J. Garrison and Associates (Ref 4). The software is a three-dimensional panel code to solve diffraction and radiation problems. A recent upgrade allows this code to address the hydrodynamic effects of two vessels in close proximity. The hydrodynamic forces produced by MORHAL2 are incorporated in Equation 1 for additional analysis using a proprietary linear equation solver, COSDYN, dedicated to the description of motion responses

for a compound floating body system connected by elastic coupling members (refer to Appendix A for details). The solver COSDYN also considers the contributions of fluid viscosity $[B_v]$, damping of the coupling member $[B_c]$, and the mechanical coupling force $[K_s]$.

After the motions of the component vessels are defined, then the coupling forces are specified by the following equations:

$$F_s = [K_s]\,X \tag{2}$$

where

$$F = F_a e^{i(k(x\cos\theta + y\cos\theta) - \omega t + \phi)} \tag{3}$$

and

F_a = amplitude of wave force

F_s = coupling force between vessels

X = vessel motion vector (12x1; 12 degrees of motion freedom)

$X = X_a\, e^{i(k(x\cos\theta + y\cos\theta) - \omega t + \phi)}$

K = wave number

ω = wave frequency (radian)

θ = wave angle

ϕ = phase angle

t = time(sec)

X_a = motion amplitude

In this analysis, 6 percent of critical roll damping is assumed for the ship to take into account the effects of viscous drag that are witnessed in roll. For the lighter, a viscous roll damping coefficient defined by Journee (Ref 5) is used:

$$\kappa = \kappa_1 + \kappa_2 * \varphi_a \tag{4}$$

where

κ = damping ratio

κ_1 = $0.0013\,(B/T)^2$

κ_2 = 0.500

φ_a = roll angle (radian)

B = beam

T = draft

The significant amplitude of the response to random waves is obtained by integrating the response spectrum over the range of wave frequencies in the following equation:

$$\sigma = \int S(\omega)\,(X_{RAO})\,d\,\omega \tag{5}$$

Significant amplitude = 2* σ
Maximum amplitude = 1.86 * Significant amplitude

where σ is the standard deviation, and $S(\omega)$ is the wave spectrum. X_{RAO} represents the response amplitude operator of absolute vessel motion, relative motion, and coupling force between vessels. X_{RAO} is obtained by solving Equations 1 and 2. The convention of the coordinate system and wave directions is presented in Figure 5. This figure also shows the position of the lighter relative to the ship, and the location of the dashspot spring.

RESULTS

The motion of the ACB lighter in six degrees of freedom is presented in Figures 6 through 9 in terms of the Response Amplitude Operator (left-hand column) and phase (right-hand column), for four orientations of wave heading (0, 45, 90, and 270 degrees). The charts pair results for simulations both with (w/I) and without (w/O) hydrodynamic interaction. The statement "without hydrodynamic interaction" implies that the vessel has been analyzed as a stand-alone body, without considering the presence of the other vessel. The statement "with hydrodynamic interaction" implies that the vessels are analyzed simultaneously as a coupled system. All motion responses presented in this report are computed at the center of gravity. Figure 10 compares the results for 90 and 270 degrees wave heading, orientations that correspond to a condition of non-sheltering and sheltering (by the T-ACS), respectively. For purposes of comparison, the response of an isolated lighter (i.e., without hydrodynamic interaction) to broadside waves is also presented. The significance of hydrodynamic coupling is clearly illustrated. It should be noted that for the most significant motions of roll, sway, and heave, the sheltering effect of the sealift vessel minimizes lighter movement. Lighter motions are less than those predicted without hydrodynamic interaction, and significantly less than those predicted for the lighter stationed on the weather side of the T-ACS.

Figures 11 through 14 provide similar chart presentations for the motions of the T-ACS in six degrees of freedom. It is noted that although the hydrodynamic effects of coupling significantly alter the behavior of the barge, the same effects have little influence on the motional responses of the large ship. This result is largely anticipated because of the substantial difference in mass between the two vessels. The lighter is too small to substantially alter the behavior of the T-ACS.

The degree to which hydrodynamic coupling does influence motion is a function of both wave heading and wave period. A significant difference in the roll response of the barge is noted in Figure 6b. Although the barge is not expected to roll or sway in head seas, it does rock rather significantly because it has been perturbed by the asymmetric excitations induced by the presence of the T-ACS. The coupled hydrodynamic reactions also enhance heave motion when broadside waves approach from the barge side of the ship, as shown in Figures 7a and 8a. Another observation is that the ship's hull provides effective sheltering to the barge. This effect

is observed by comparing the barge responses to beam waves approaching from the barge side (Figure 8, wave heading = 90 degrees) and the ship side (Figure 4, wave heading = 270 degrees). The barge is noticeably much more steady in sway, heave, and roll motions when it is positioned along the leeward side. Unlike the barge response that is affected by coupling, the ship response is barely influenced at all by the presence of the barge. Both the motions with and without hydrodynamic coupling are essentially identical, as shown in Figures 11 through 14.

The effectiveness of sheltering provided by the ***Keystone State*** is further demonstrated by scrutinizing the relative motions predicted between the two vessels in sea state 3 as a function of wave heading, as presented in Figure 15. Three values of linear stiffness and three values of dashpot damping are paired to produce nine elastic combinations characteristic of the coupling structure. In the simulation model, the coupling structure restricts motion only in sway. It is observed that motion responses in all modes are smaller with the barge on the leeward side of the ship (i.e., wave heading greater than 180 degrees) when compared to the barge on the windward side (i.e., wave heading less than 180 degrees). Figure 16 presents collaborating results for conditions representative of sea state 4.

It is most interesting to note that a coupling structure exhibiting a spring stiffness within the range of values consistent with typical form fenders may actually amplify the relative motions in sway and roll. Figure 16b shows that sway amplitude at a stiffness value of 40 kips/ft exceeds those sway amplitudes predicted at stiffness values of 10 and 70 kips/ft. The implication drawn from these predictions is that providing a stiffer constraint may not provide the desired remedy to suppressing undesirable relative motions. As anticipated, the percentage of damping provided by the dashpot also affects relative motion, although not to the degree that stiffness does. Figure 17 summarizes the relative motions of the T-ACS as observed from the barge in regular 5-foot waves. These relative motions can be significant, primarily near those wave frequencies in ss3 and ss4 that carry the most energy. A proper measure of protection is therefore required to safely buffer each hull against the wild excitations created by hydrodynamic coupling.

Figures 18 and 19 present summary information on the nature of the coupling force predicted between vessels. Figure 18 considers a 5-foot regular wave approaching at the two most active wave headings (90 and 270 degrees). From top to bottom, the three charts display the manner in which the coupling force varies with spring stiffness (10, 40, and 70 kips/ft), percent damping (4, 7, and 10 percent), and wave period for the two specified wave headings. The results present a clear comparison between the effect of positioning the barge on the weather side (i.e., wave heading 90 degrees) versus staging it on the leeward side (i.e., wave heading 270 degrees). The coupling force is clearly a function of wave period, as expected given the hydrodynamic characteristics of the floating bodies. It is important to note that the coupling force attains a maximum value at wave period 6 seconds, a period that carries the most energy within the sea state 3 spectrum.

Figure 18 indicates that, in general, the coupling forces encountered when the barge is sheltered by the ship are dramatically smaller for wave periods less than 8 seconds, given that the other characteristics of the coupling structure are held constant. This difference may be as great as 60 percent at wave frequencies near 6 seconds. For longer waves, the lighter more or less moves in phase with the T-ACS, and the advantages of hiding behind the ship are greatly diminished. Figure 18 also indicates that dashpot damping may be effective in reducing the maximum coupling force by as much as 20 percent.

The conclusions drawn from the results in Figure 18 are reinforced by the results presented in Figure 19. From top to bottom, the three charts in Figure 19 display the manner in which the coupling force varies with wave period (6, 8, and 10 seconds), percent damping (4, 7, and 10 percent), and wave heading (0 to 360 degrees). It may be observed that at a short wave period of 6 seconds the stiffest spring constant produces the largest coupling force, whereas at longer 8- and 10-second periods the mid-value stiffness actually produces the largest coupling force. It is also noted that the coupling force fluctuates with wave heading in a manner similar to changes in relative motion between lighter and ship.

From top to bottom, respectively, Figure 20 highlights the coupling forces predicted in random seaways of ss3 and ss4 magnitude, again as a function of wave heading. Results are presented for nine paired values of spring stiffness and dashpot damping. The general profiles defining the coupling force in terms of wave heading are similar to those witnessed in Figure 19 for a regular wave. The maximum forces corresponding to a lighter attached to the weather side and the leeward side are 400 and 230 tons, respectively, in ss3, and 500 tons and 270 tons, respectively, in ss4.

CONCLUSIONS AND RECOMMENDATIONS

1. The hydrodynamic response of the ACB lighter to sea state 3 exposure is very pronounced, whereas the T-ACS is stable and motions are much more subdued.

2. Mechanical and fluid coupling between vessels has a significant effect on the overall dynamic behavior of the system, although the significant size difference between vessels results in a lopsided hydrodynamic marriage. The motional response of the lighter is entirely altered by the presence of the large ship, whereas the behavior of the ship is minimally influenced by interaction with the small lighter. The coupling effects change the nature of relative motion between the two vessels dramatically, both in magnitude and phase.

3. The lighter is excited most strongly by waves periods of 4 to 6 seconds, a range that coincides with the frequency band of greatest wave energy in ss3.

4. The ship provides an effective means of sheltering the lighter. An ACB lighter stationed on the weather side of the T-ACS will welter severely in sea state 3 conditions, whereas motions may be reduced by as much as 60 percent with the lighter sheltered on the leeward side. Without the protection of the sealift vessel, the lighter-to-ship interface structure will require appreciably more engineering design and cost. The advantages of strategic placement are clear.

5. The effects and counter-effects of mechanical coupling may impose a significant influence on the overall dynamics of motion. Predictions made by the parametric study indicate that resonance is highly likely and may be a significant factor in the design of some structural members. It is found that larger and stiffer components do not necessarily mitigate the relative motions between vessels. It is critical to design an interface structure, including fender and mooring systems, that properly tunes both stiffness and damping so that system resonance frequencies are separated from the peak frequencies of incident wave energy. Additional studies are required to identify optimum pairs of stiffness and damping consistent

with the various combinations of sealift vessel and watercraft that will be active during a JLOTS operation.

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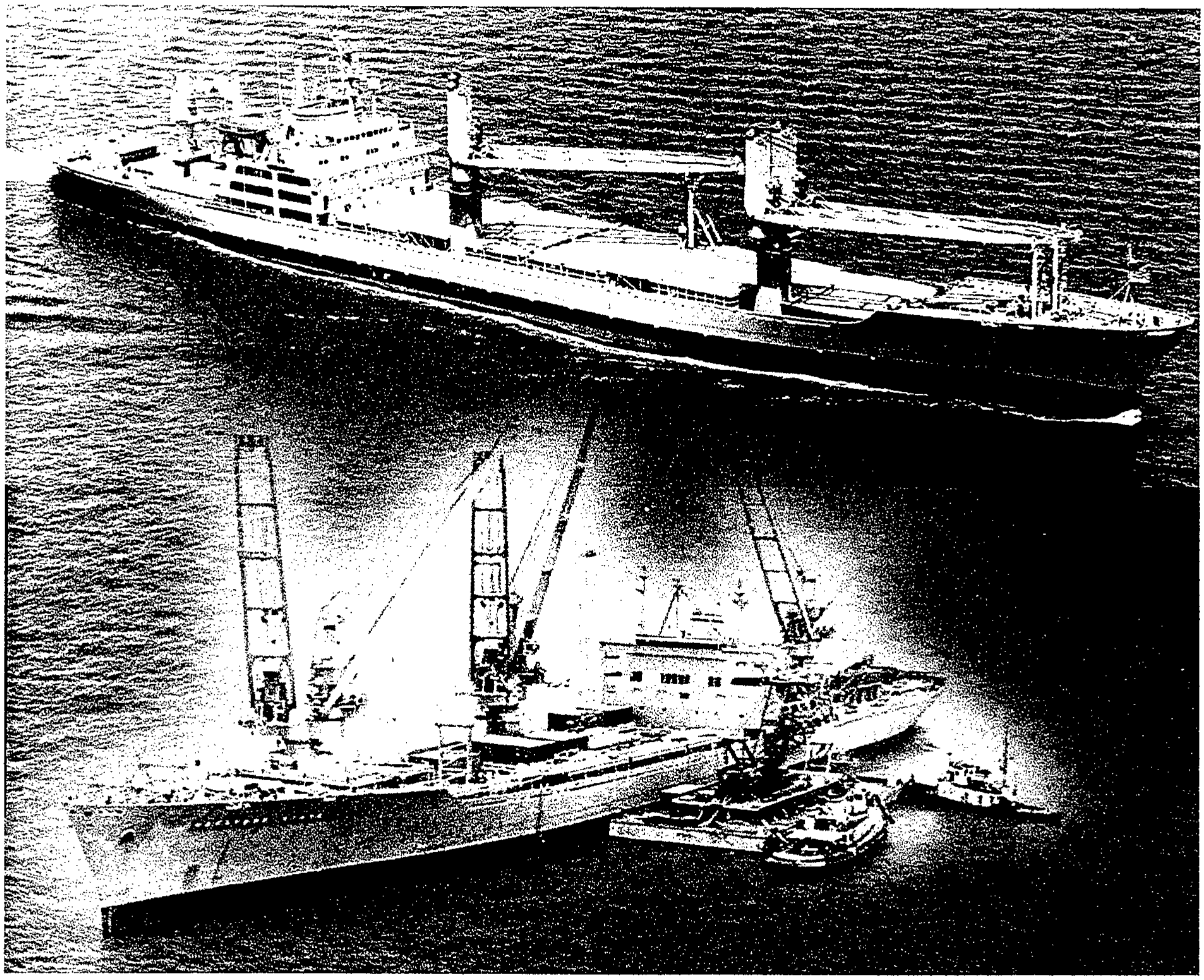


Figure 1. T-ACS transferring cargo ship during a JLOTS operation

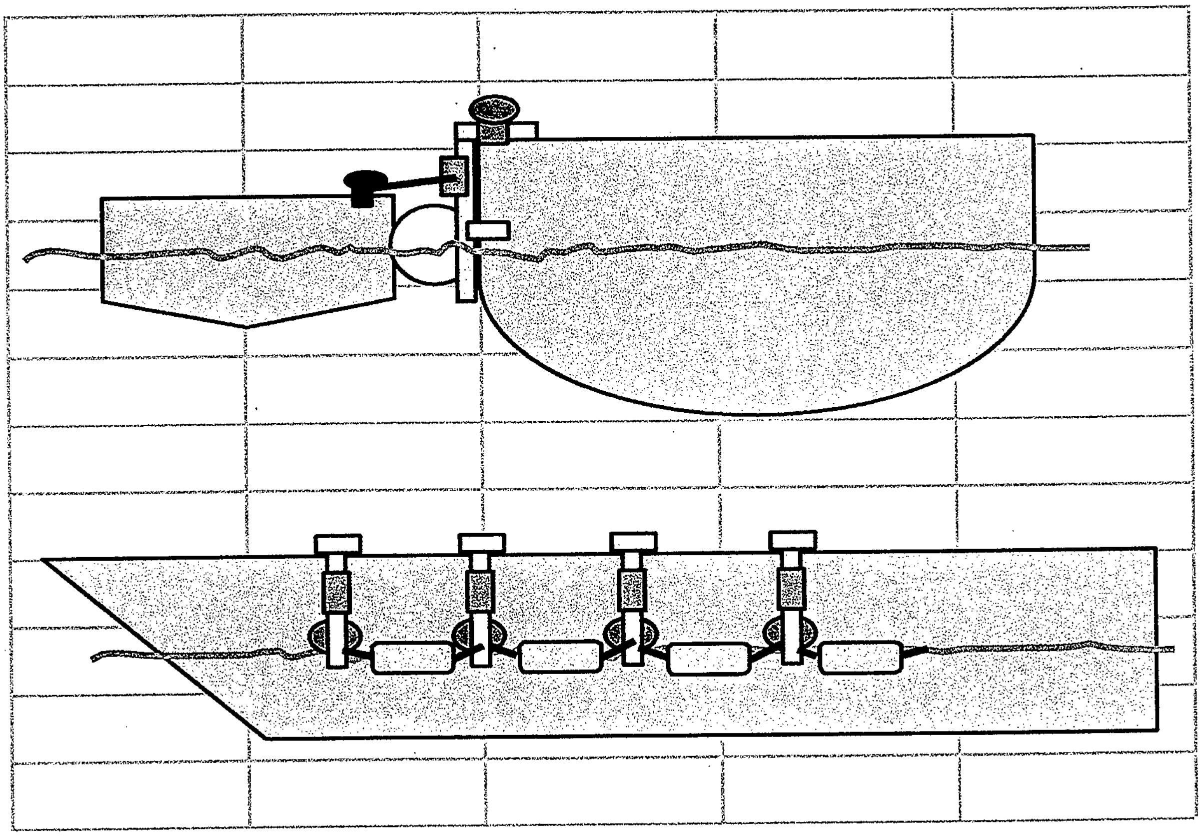


Figure 2. Proposed concept of interface structures for high sea state docking.

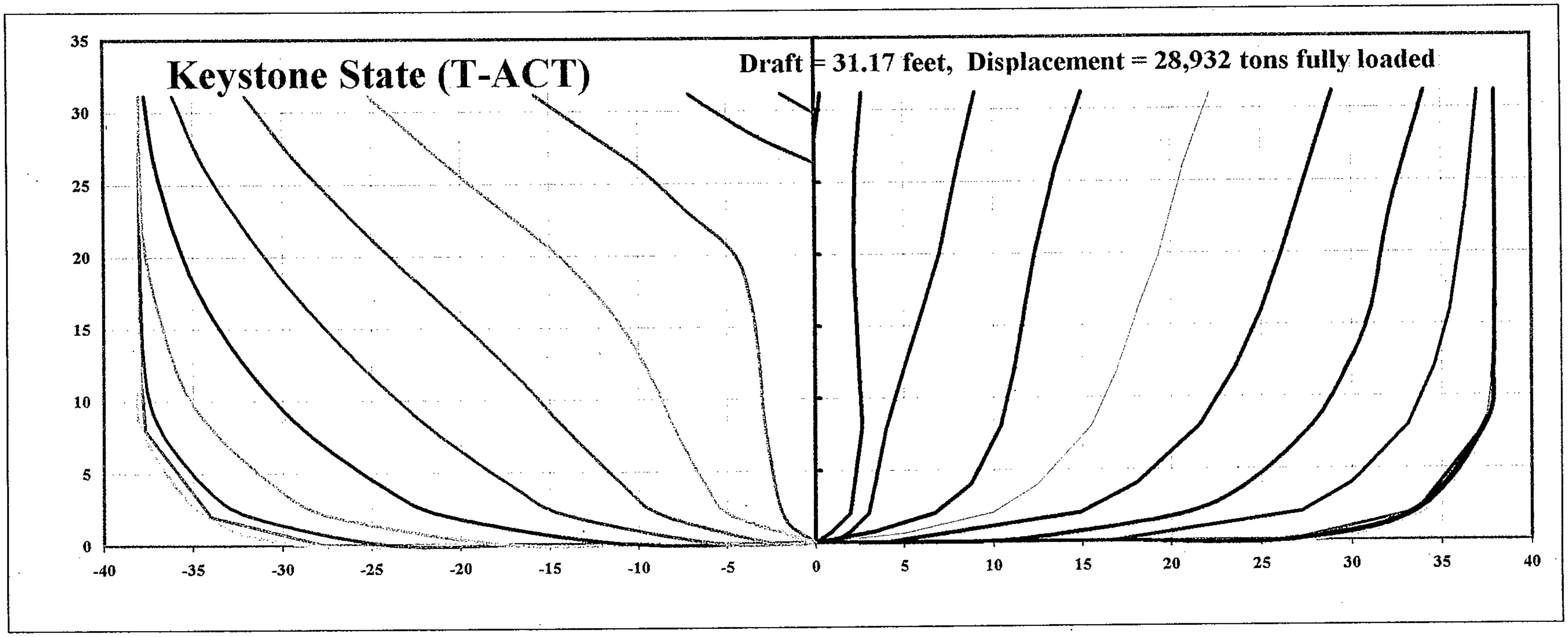


Figure 3 Body plan of the T-ACS sealift vessel Keystone State

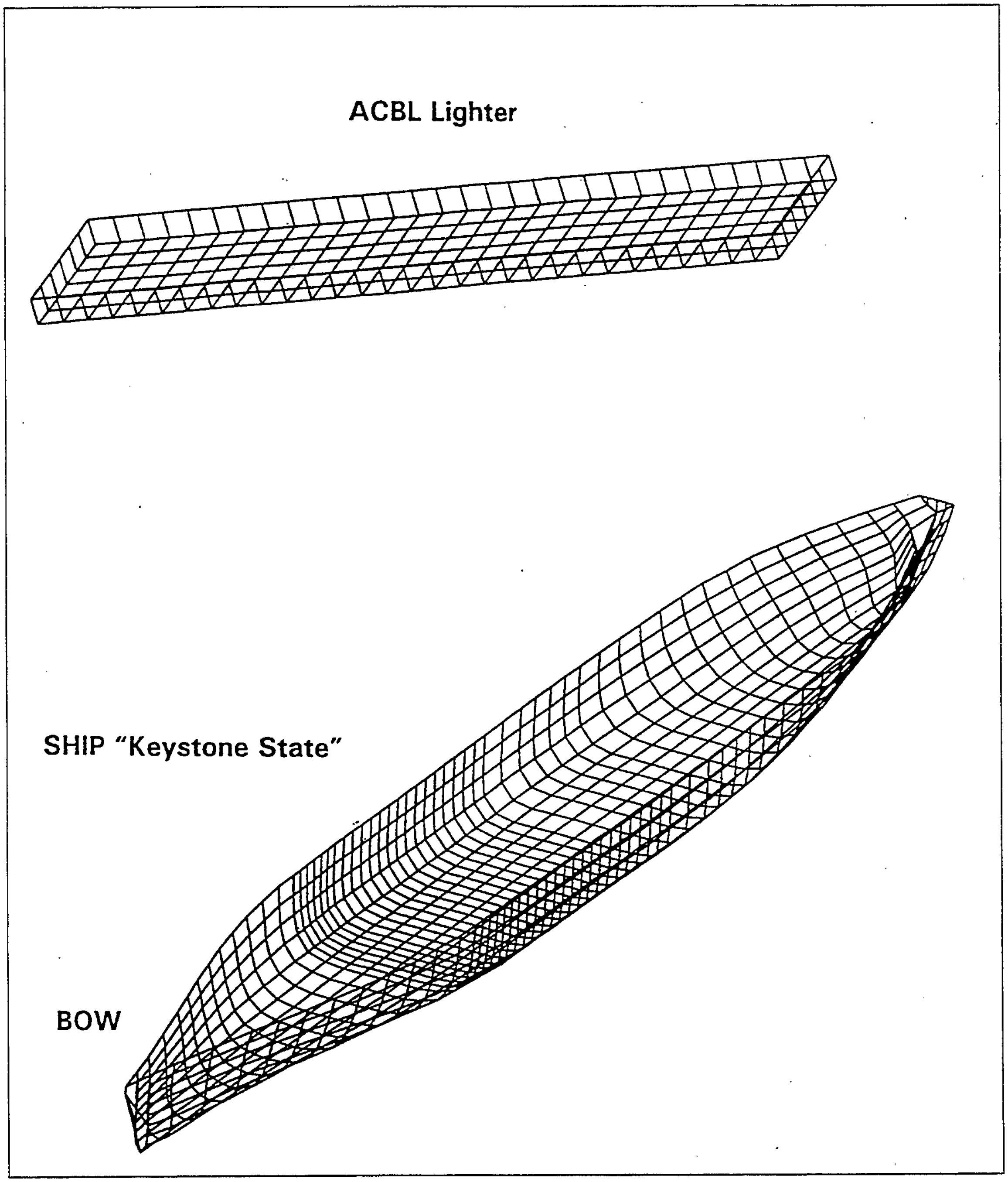


Figure 4. Finite element grids for ACB lighter and T-ACS.

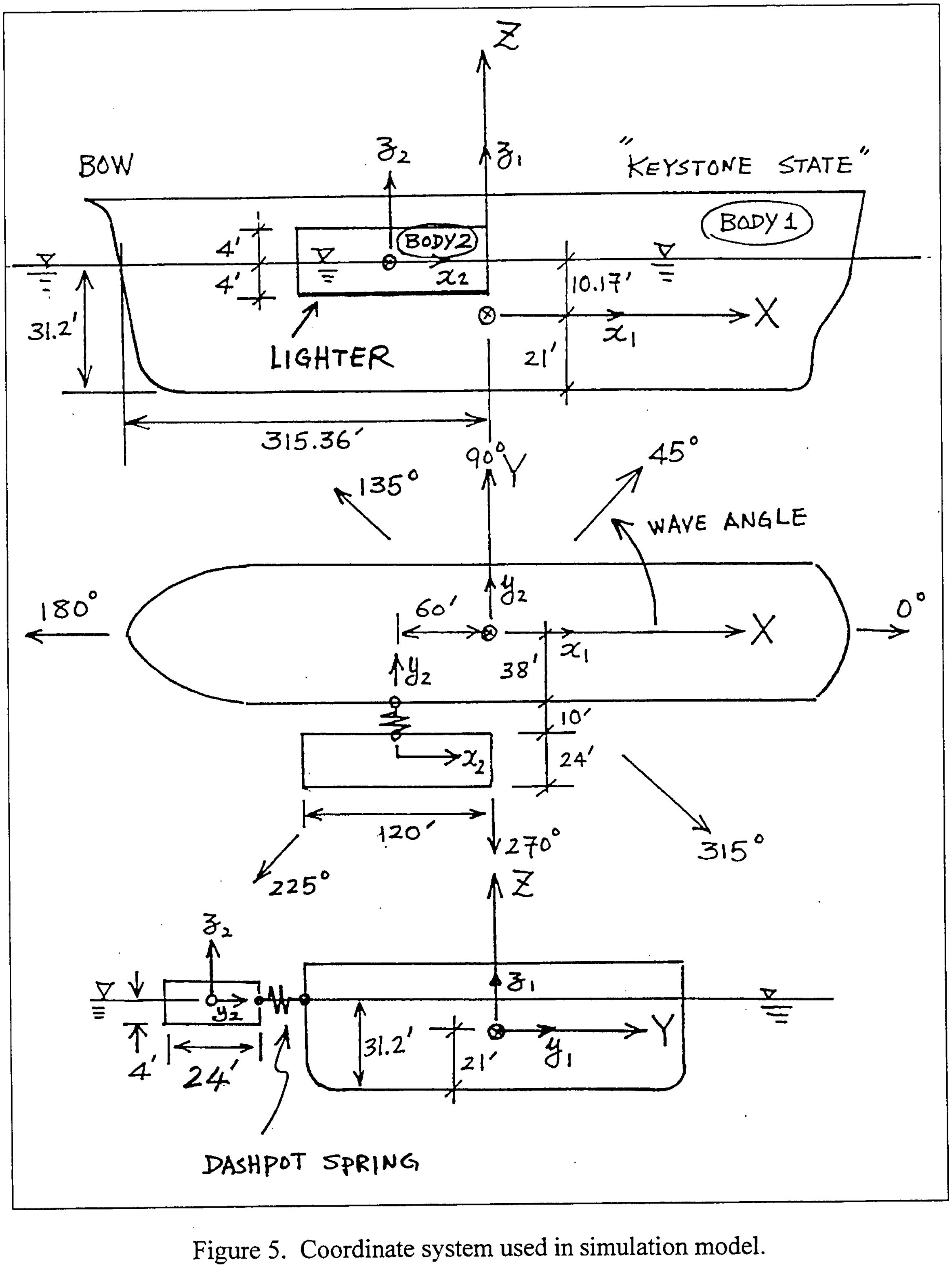


Figure 5. Coordinate system used in simulation model.

Wave heading (deg): **360 (or 0)**

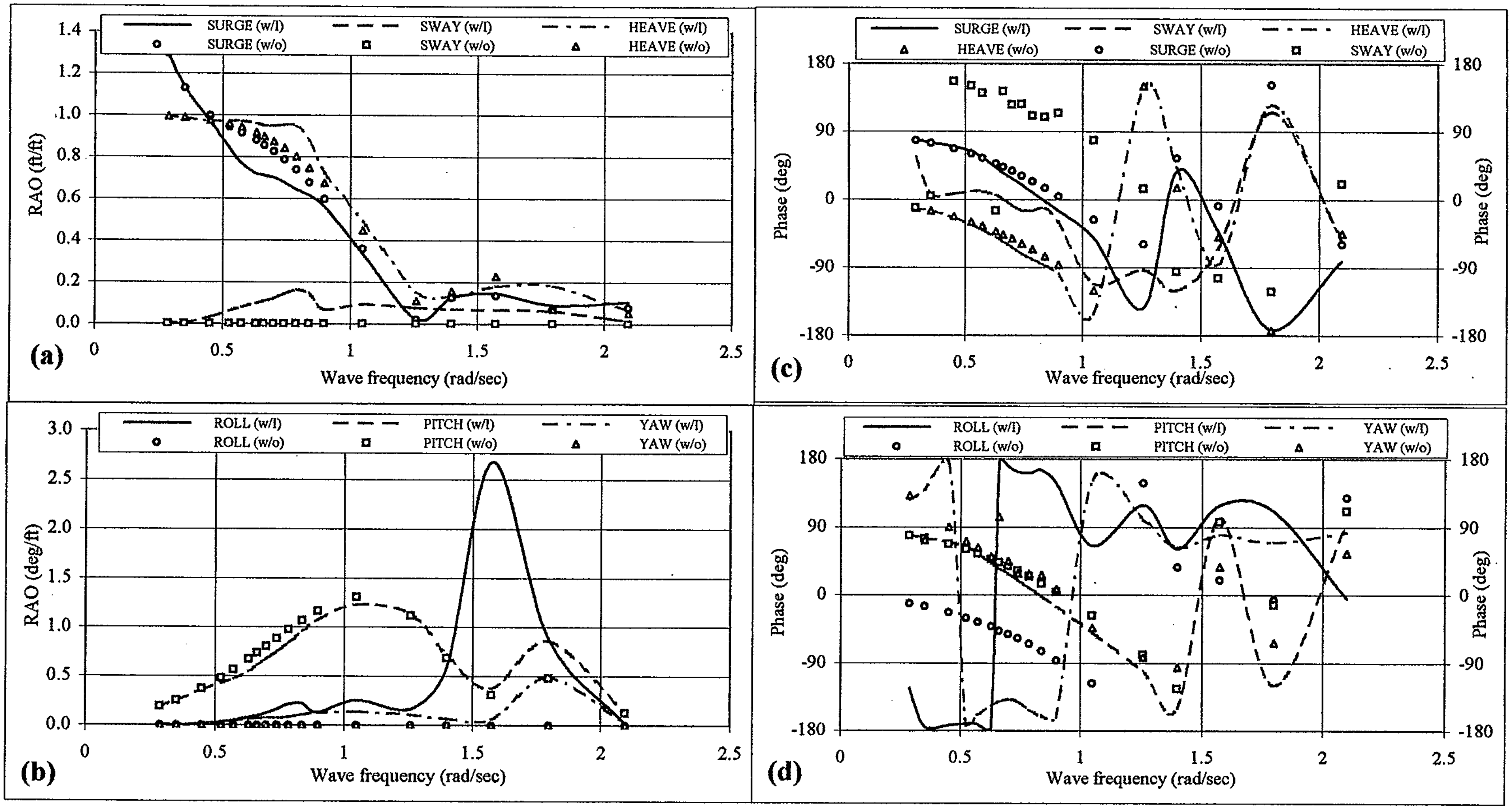


Figure 6. Motion responses of ACB lighter (wave heading = 360 (or 0) degrees).

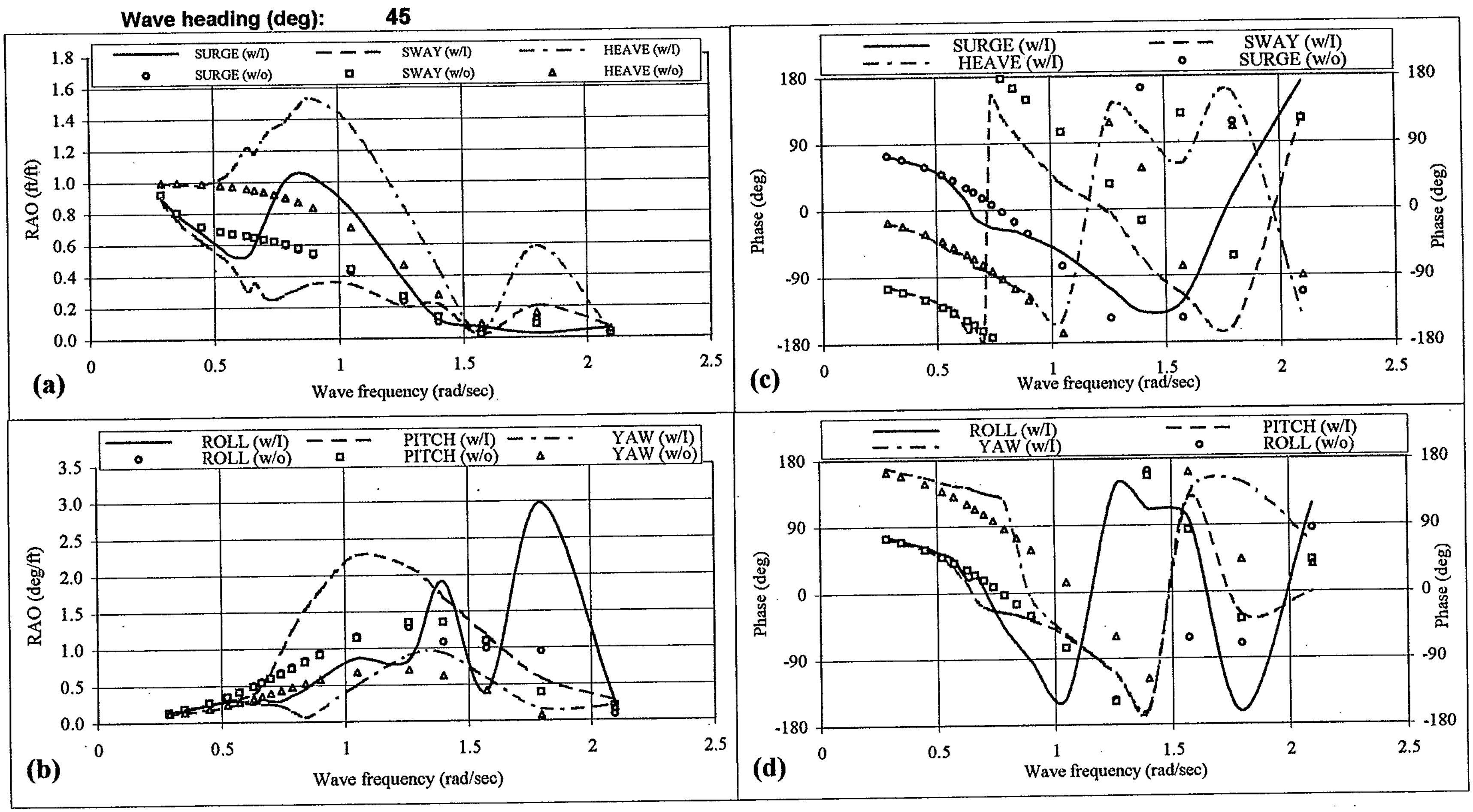


Figure 7. Motion responses of ACB lighter (wave heading = 45 degrees).

Wave heading (deg): 90

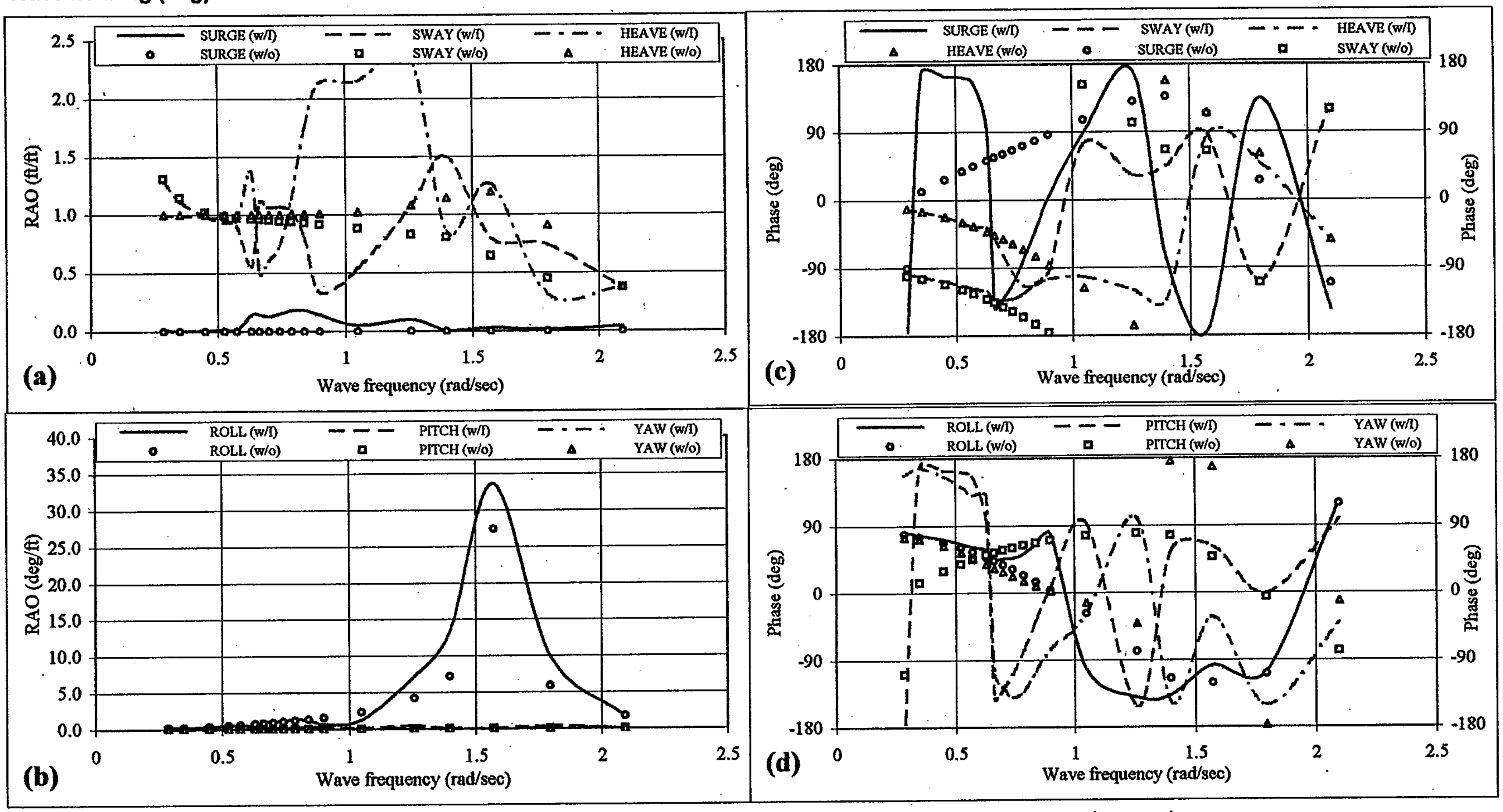


Figure 8. Motion responses of ACB lighter (wave heading = 90 degrees).

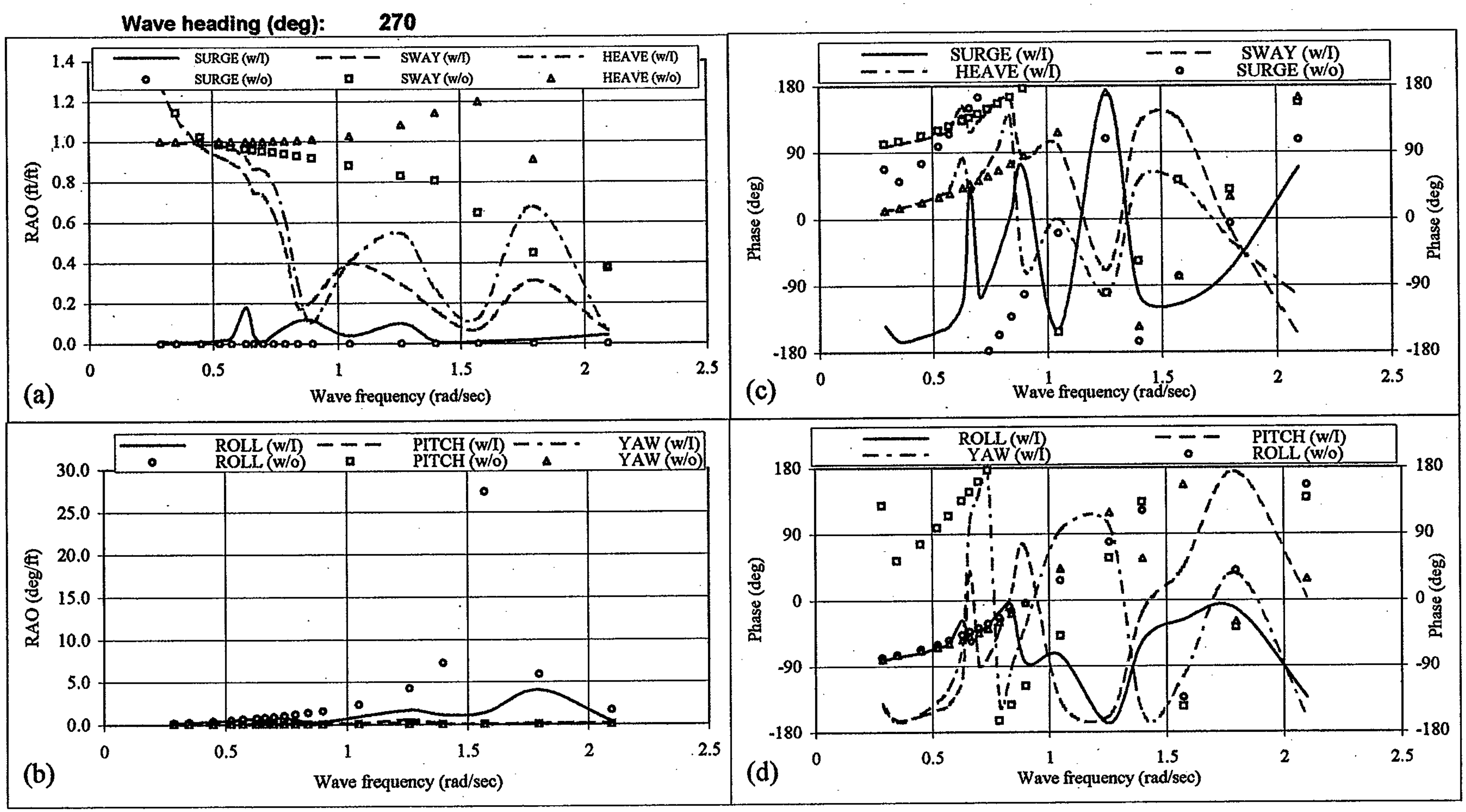


Figure 9. Motion responses of ACB lighter (wave heading = 270 degrees).

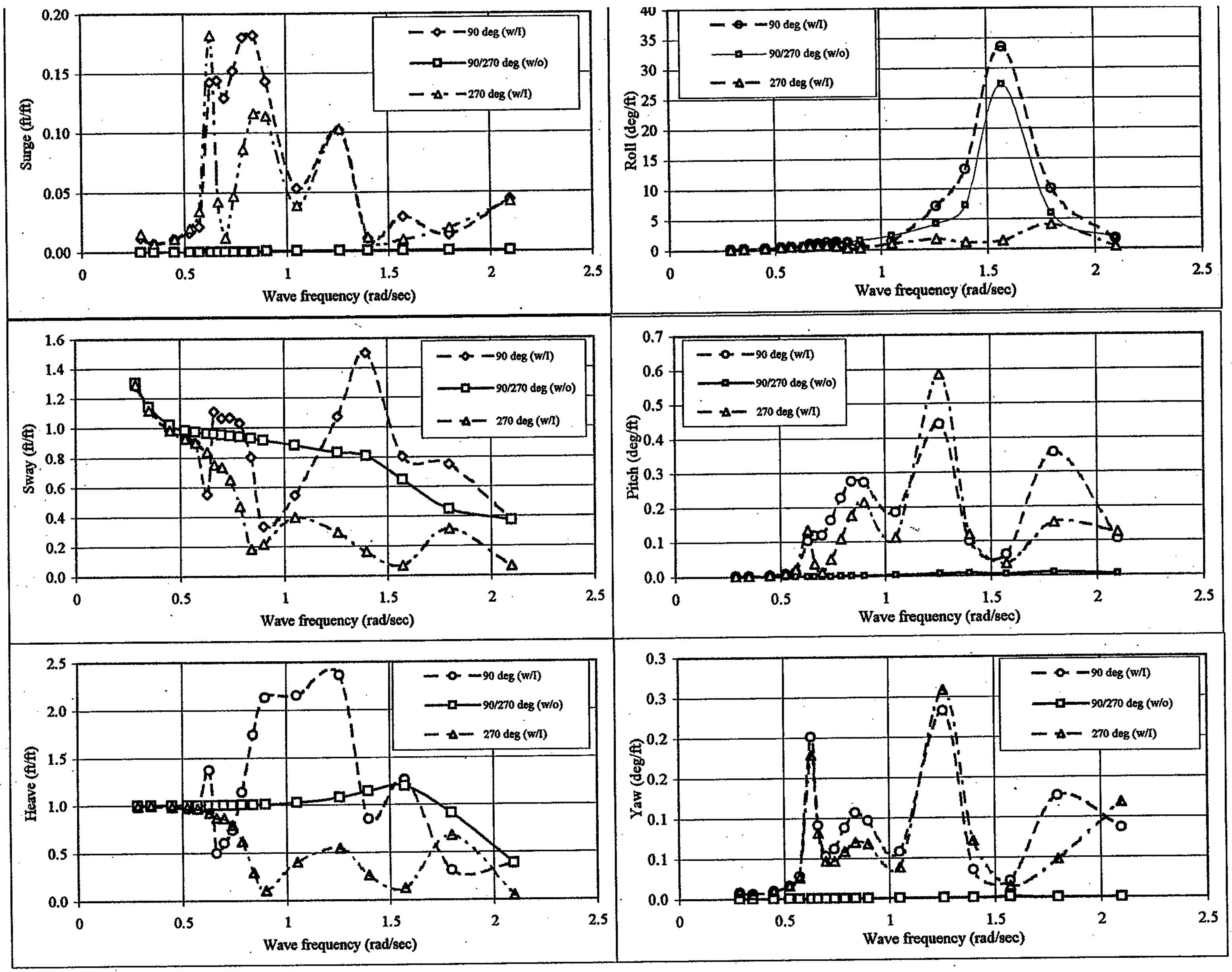


Figure 10. Sheltering effect of the T-ACS - comparison of barge response in waves 90 and 270 degrees.

Wave heading (deg): 360 or 0

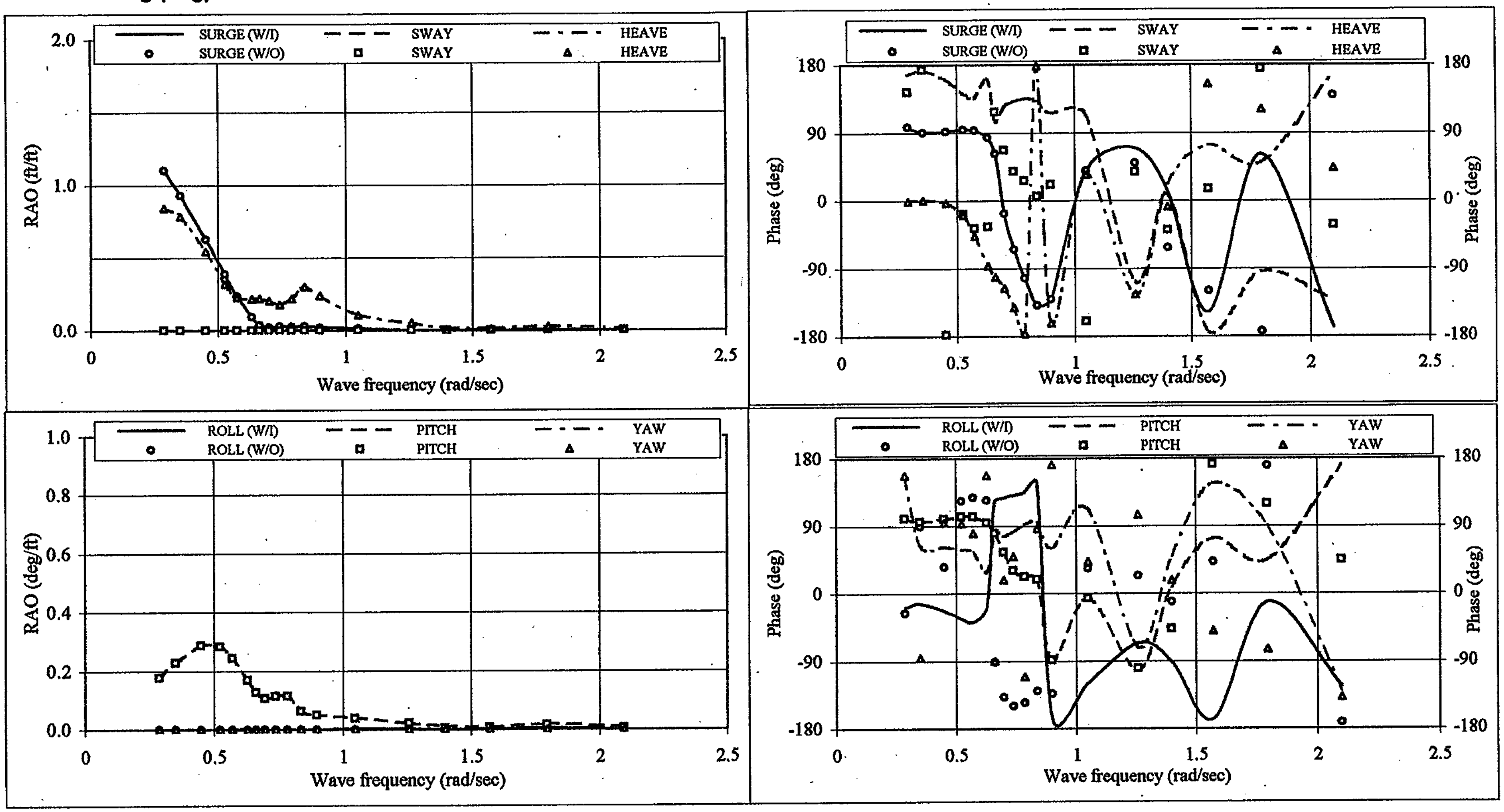


Figure 11. Motion responses of the T-ACS ship (wave heading = 360 (or 0) degrees).

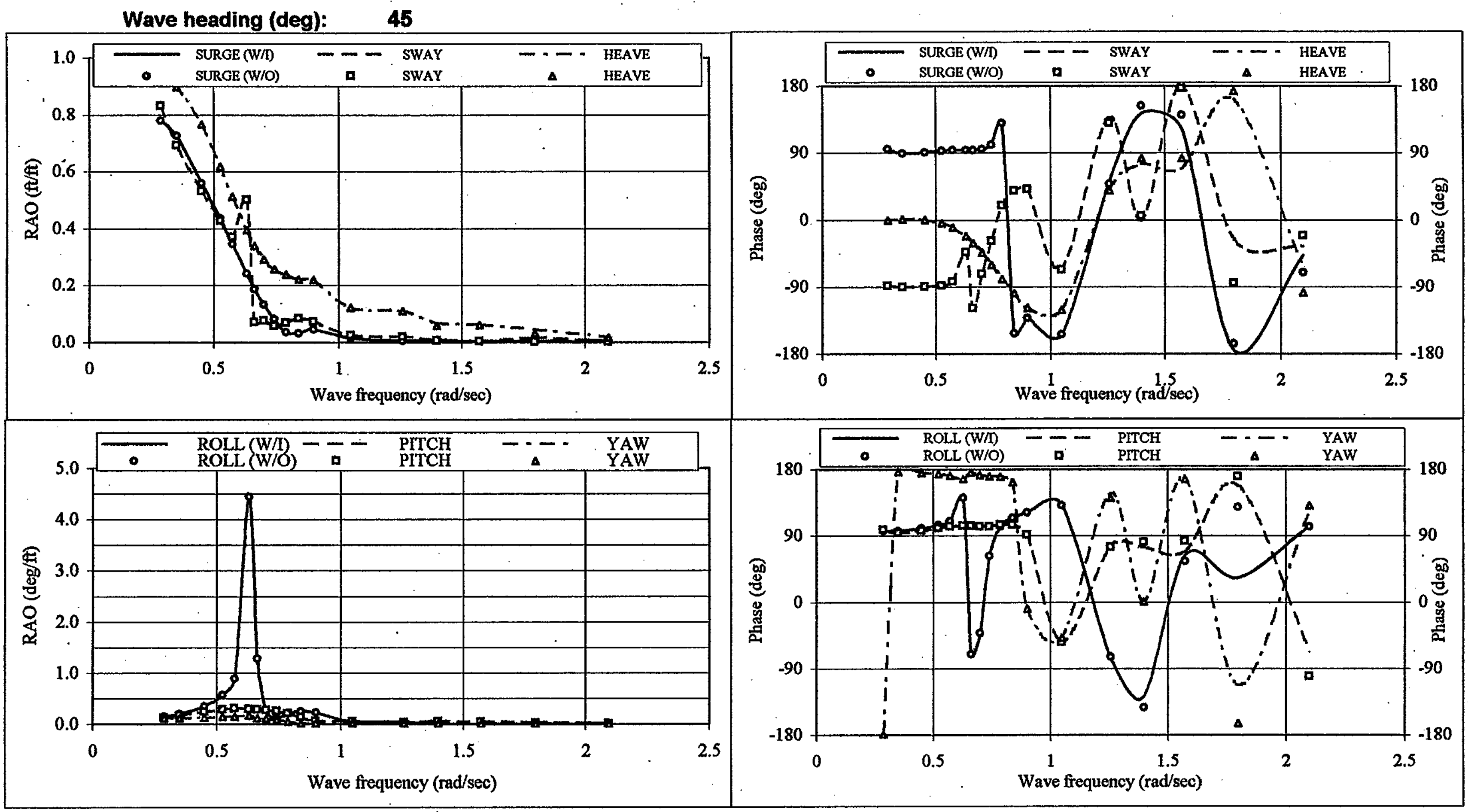


Figure 12. Motion responses of the T-ACS ship (wave heading = 45 degrees).

Wave heading (deg): 90

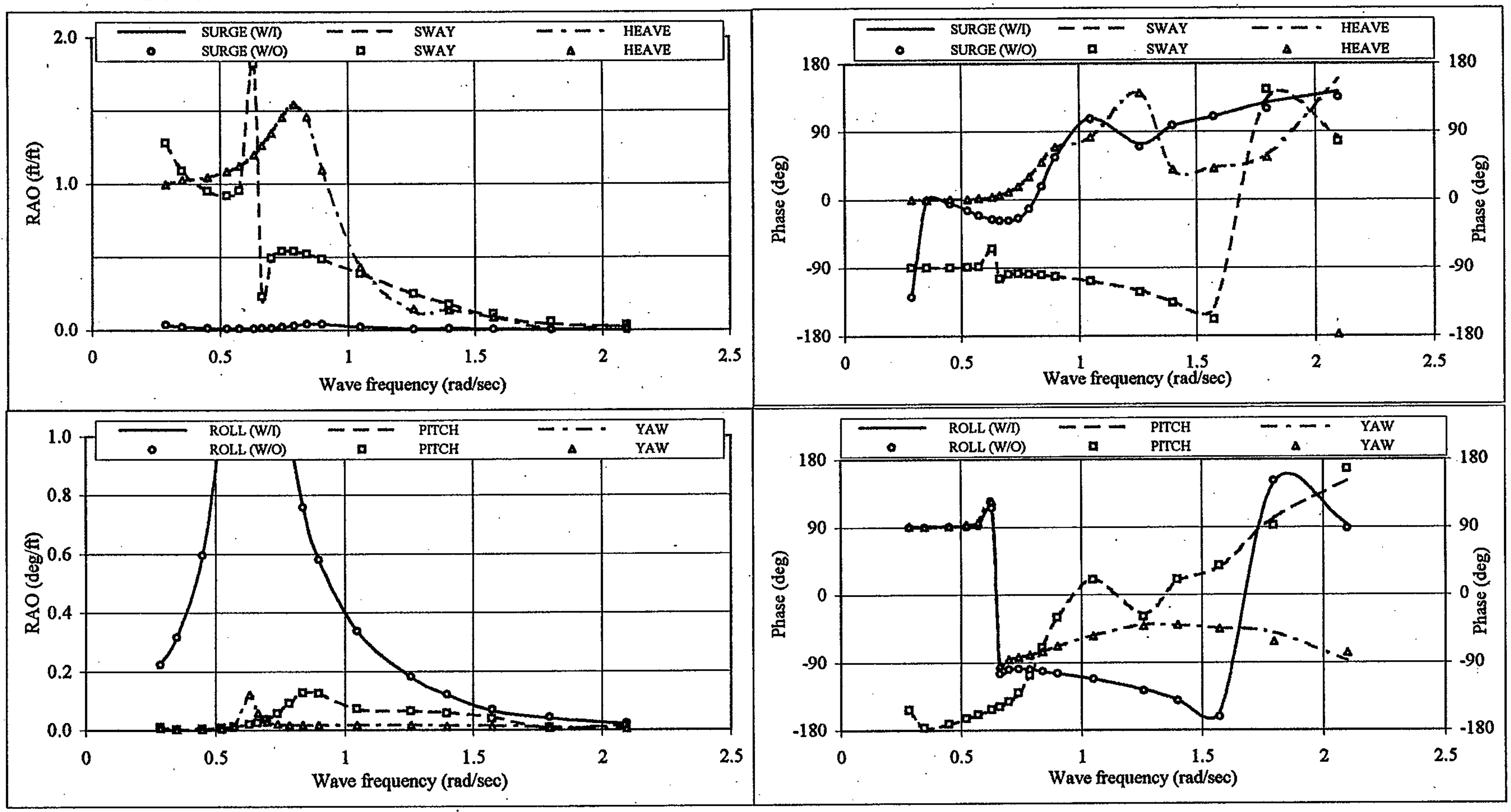


Figure 13. Motion responsess of the T-ACS ship (wave heading = 90 degrees).

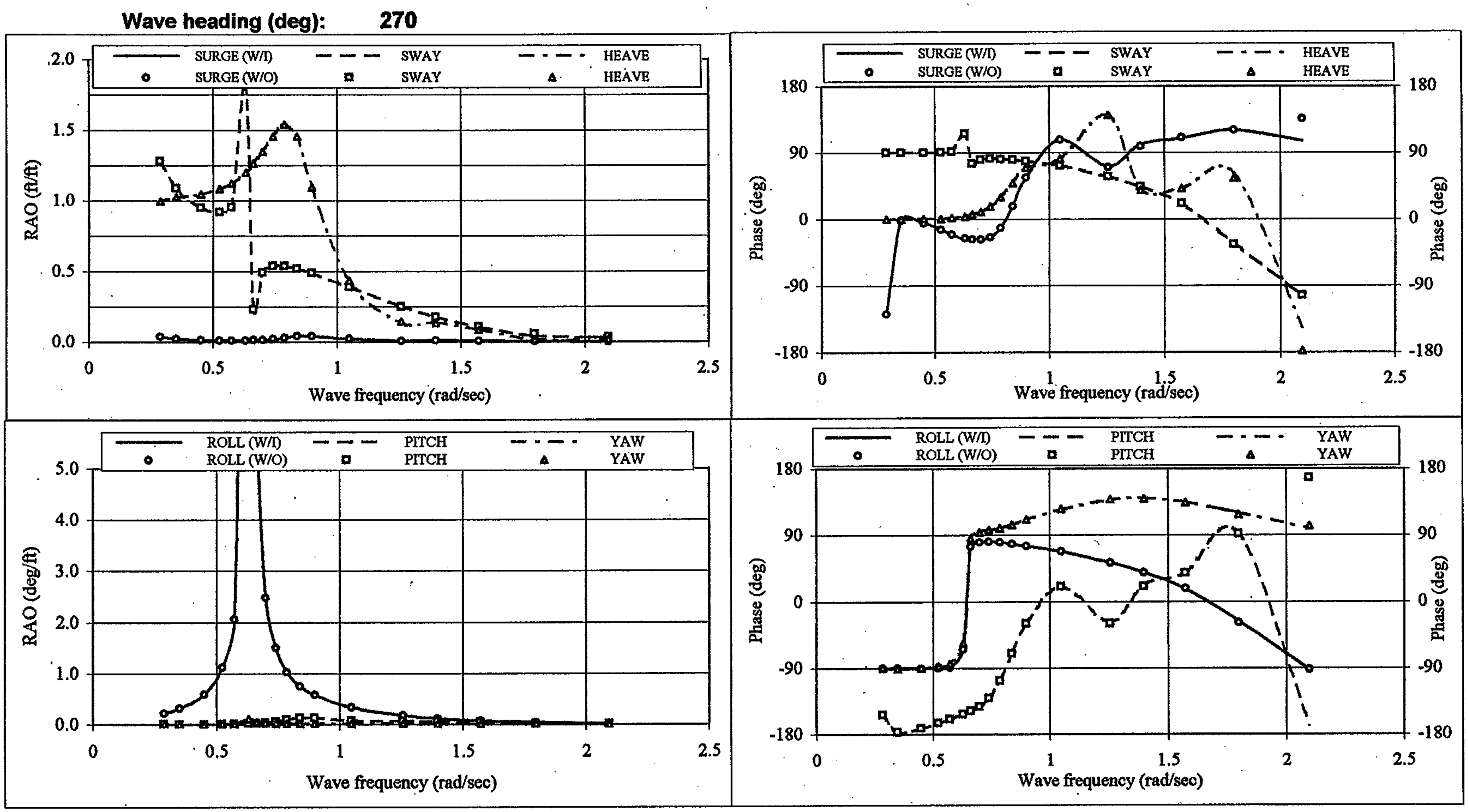


Figure 14. Motion responses of the T-ACS ship (wave heading = 270 degrees).

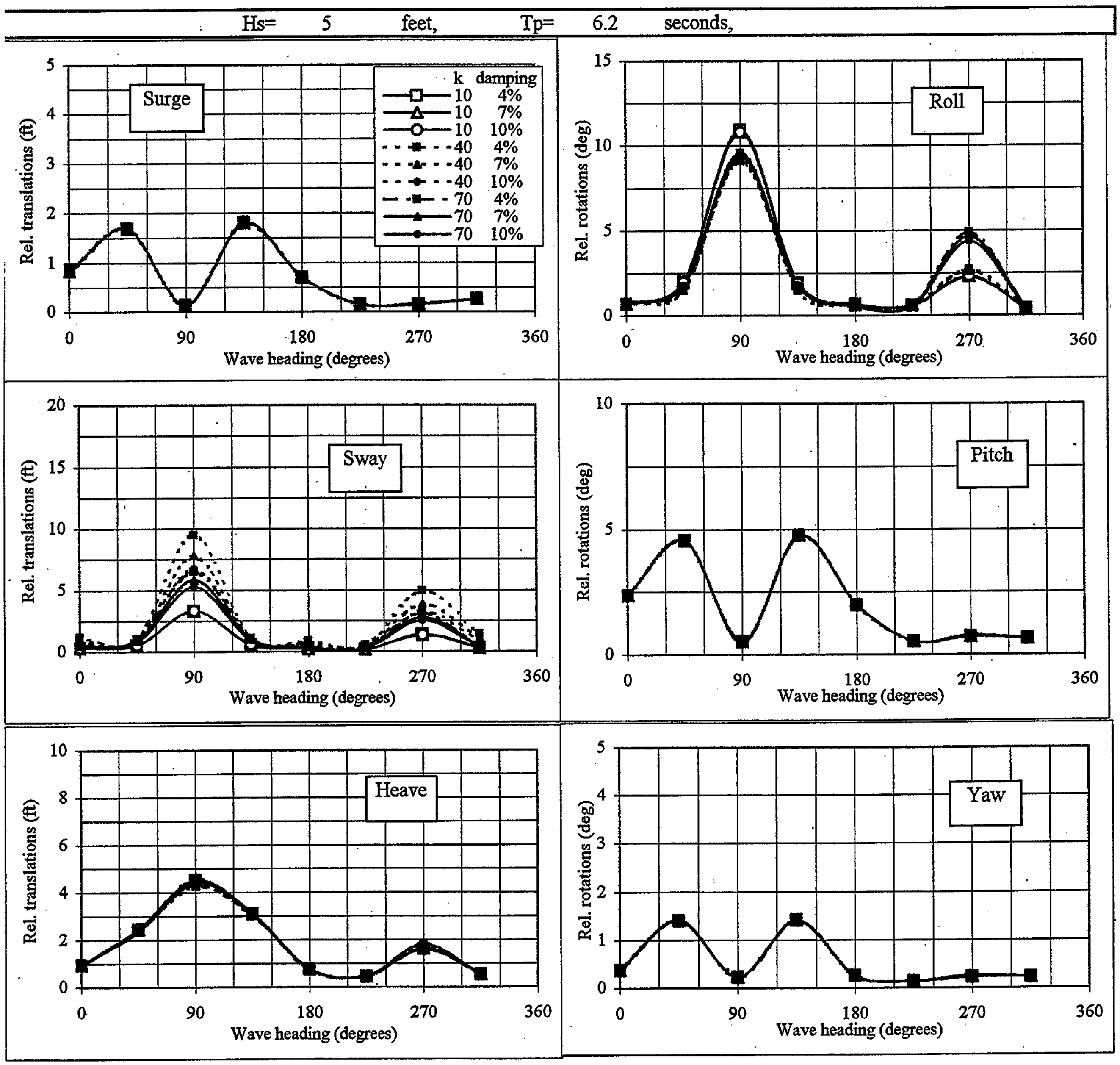


Figure 15. Relative motion of the T-ACS as seen from the ACB lighter in random seaway (ss3).

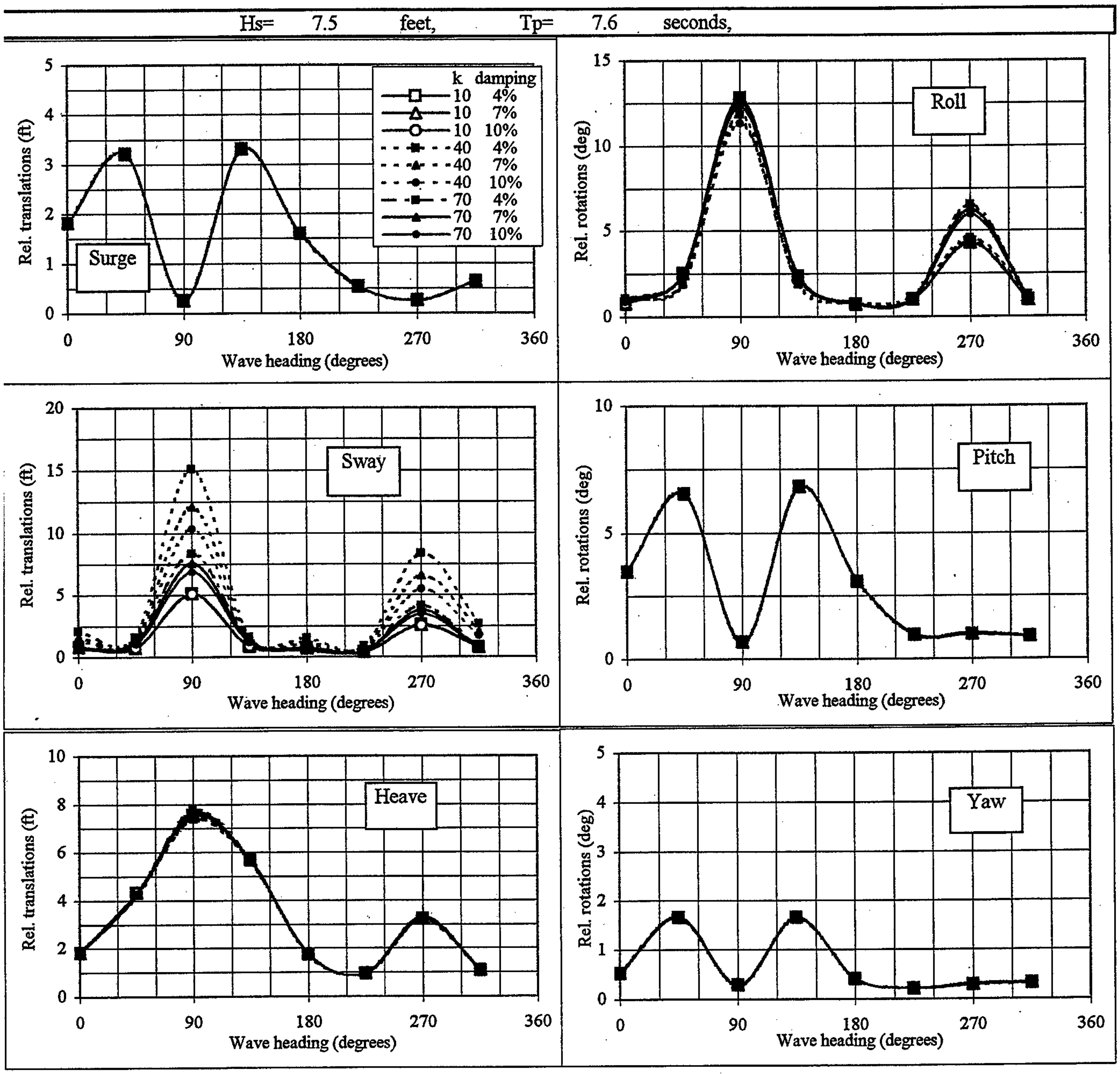
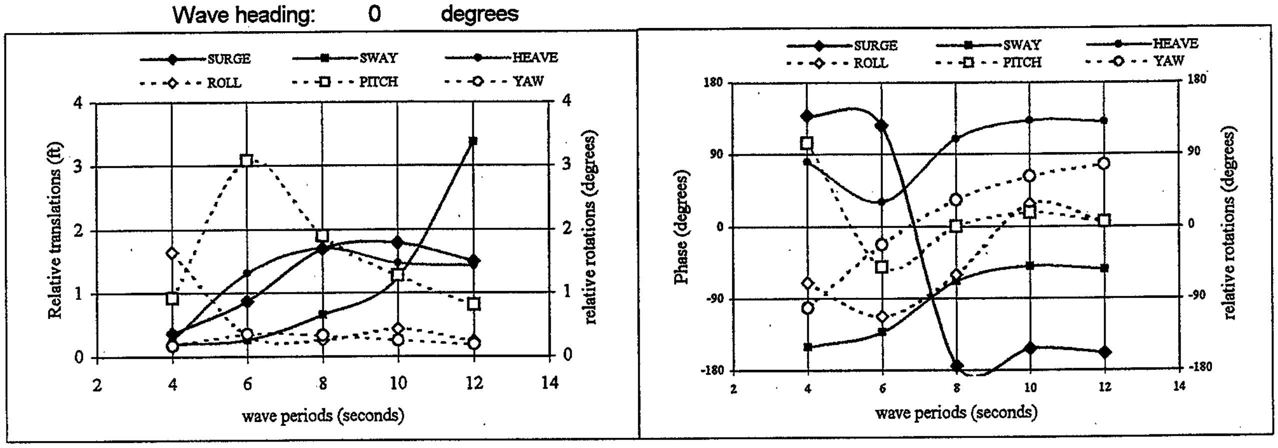
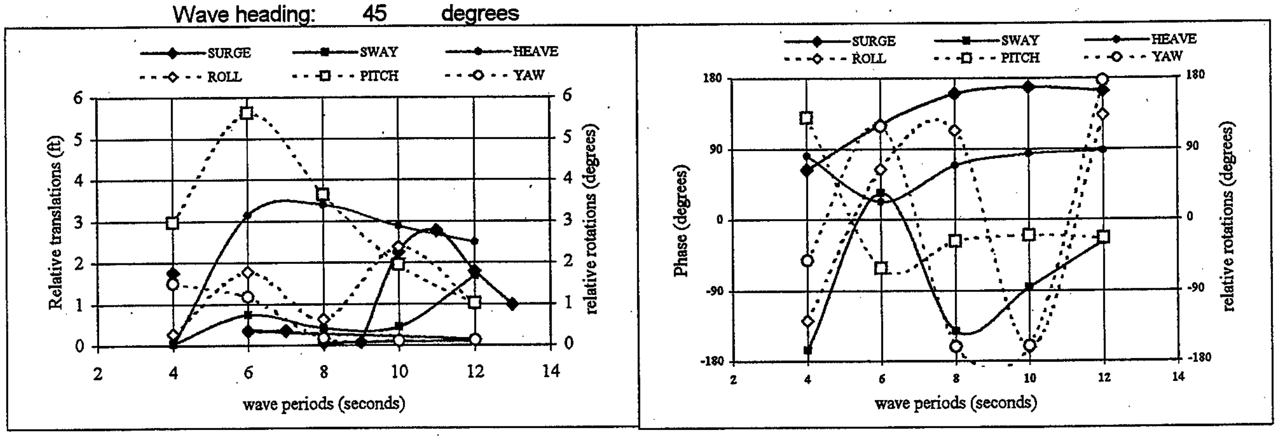


Figure 16. Relative motion of the T-ACS as seen from the ACB lighter in random seaway (ss4).

Wave heading: 0 degrees



Wave heading: 45 degrees



Wave heading: 90 degrees

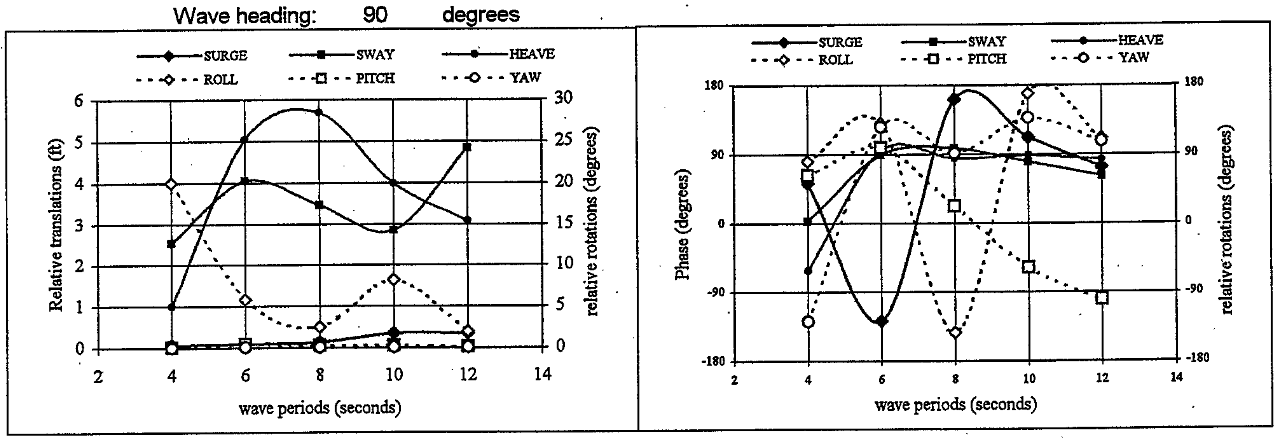
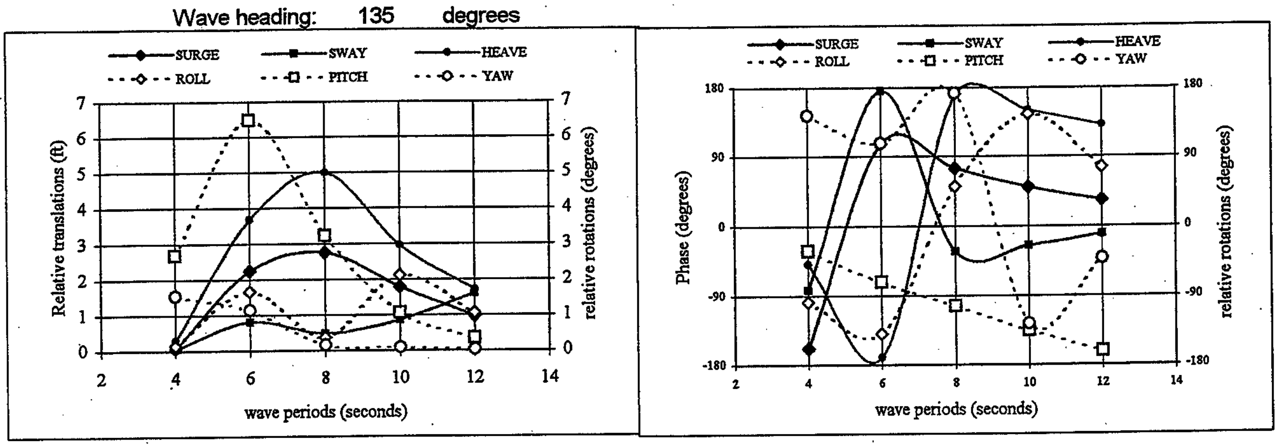
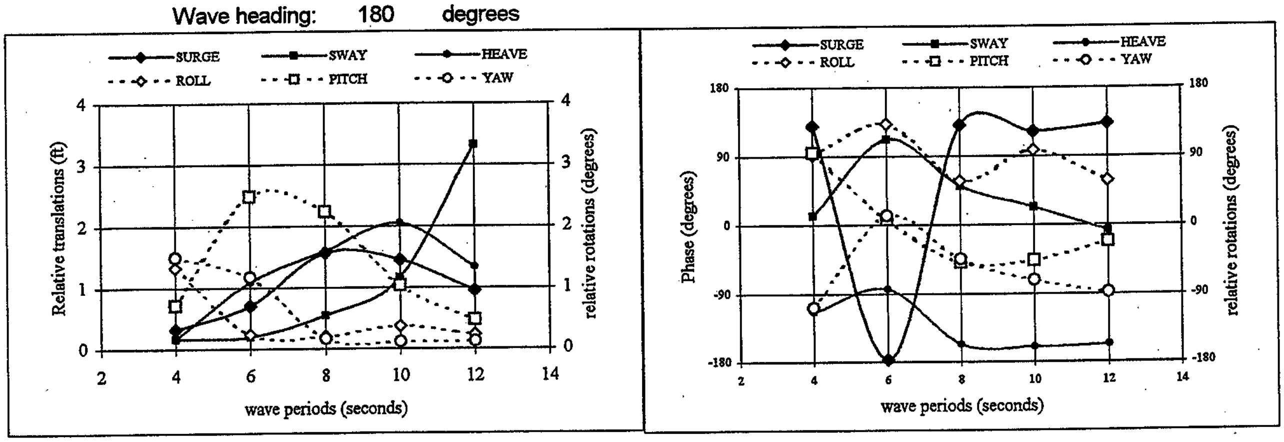


Figure 17. Relative motions between lighter and T-ACS in regular waves as a function of wave period for k = 10 Kips/ft and 4% damping.

Wave heading: 135 degrees



Wave heading: 180 degrees



Wave heading: 225 degrees

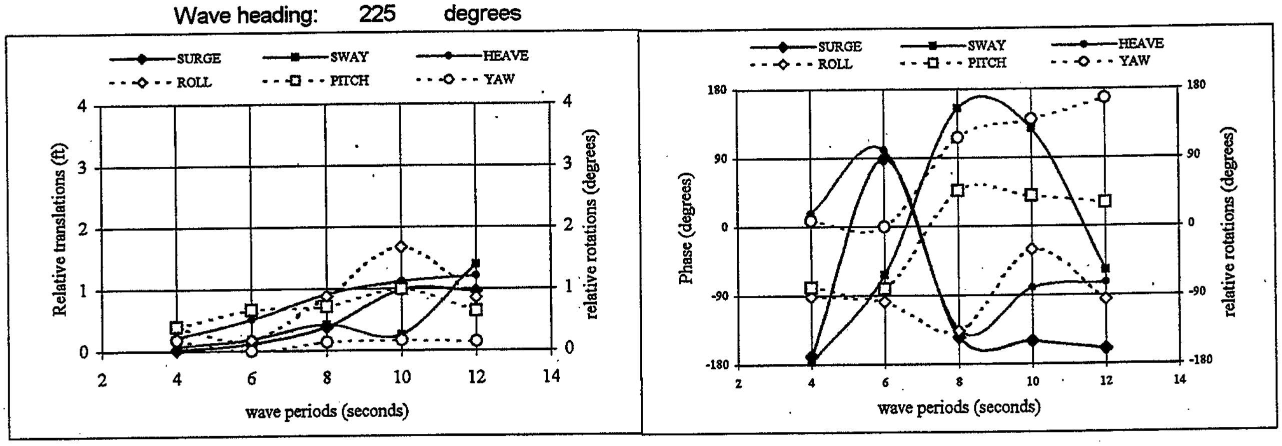
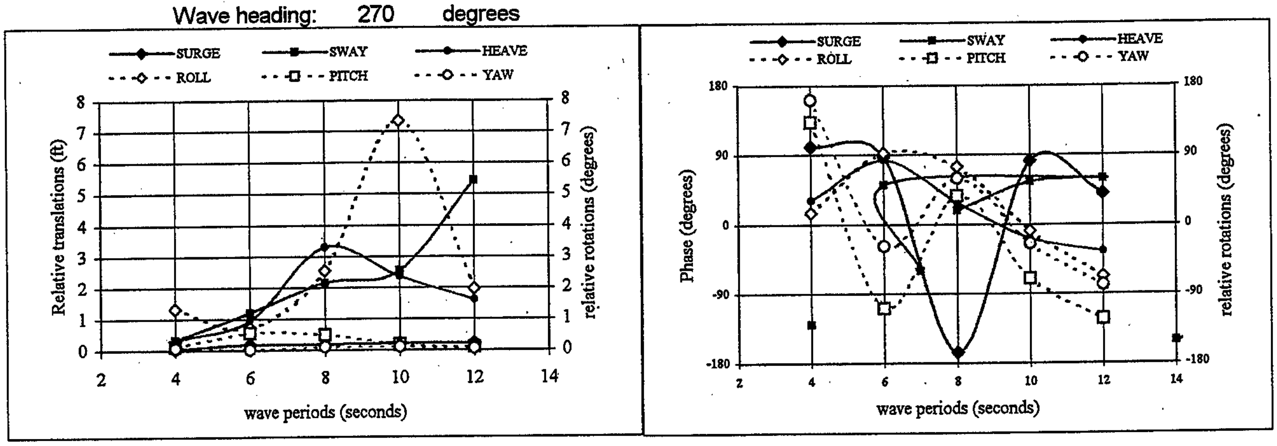


Figure 17. Continued.

Wave heading: 270 degrees



Wave heading: 315 degrees

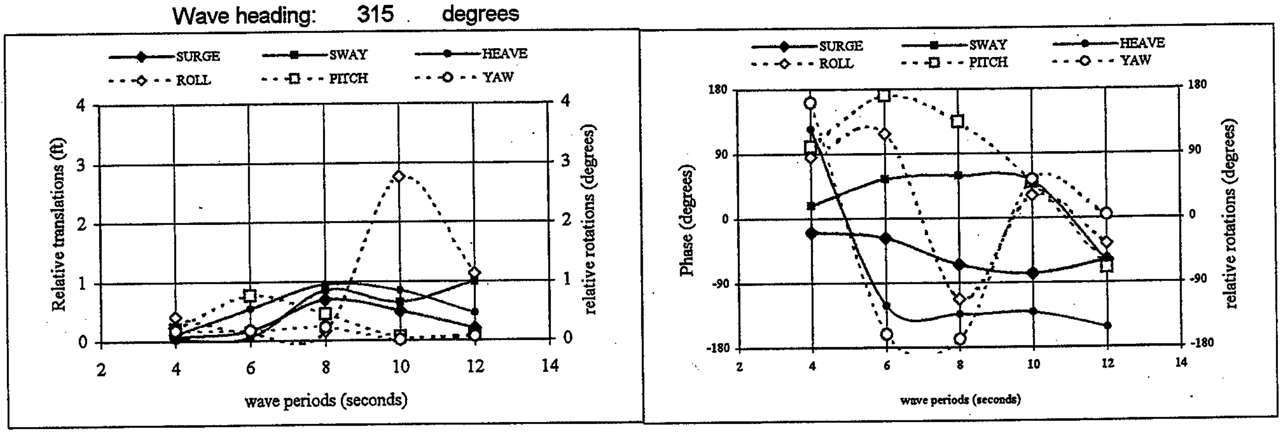


Figure 17. Continued

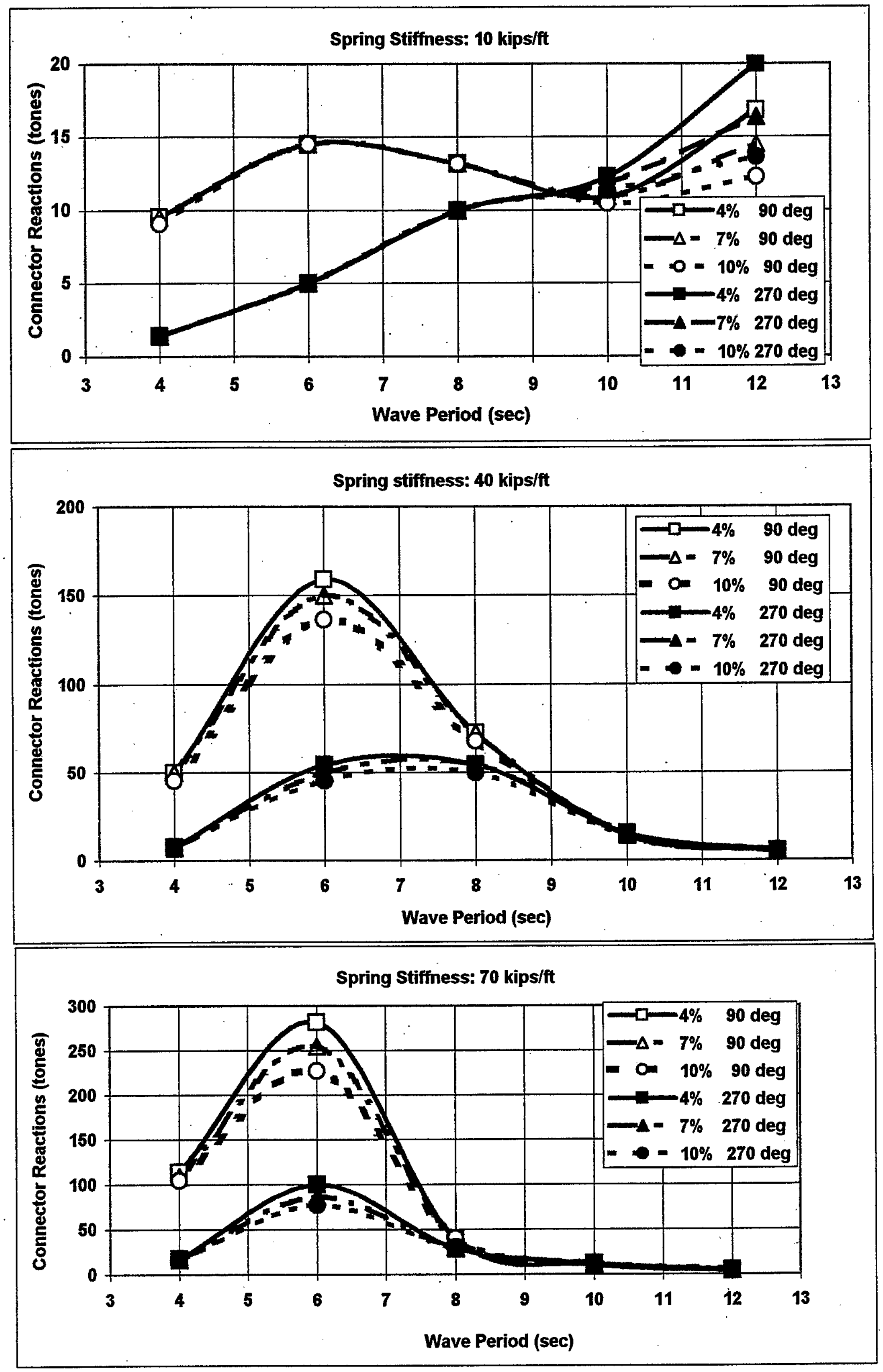


Figure 18. Coupling force versus wave period.

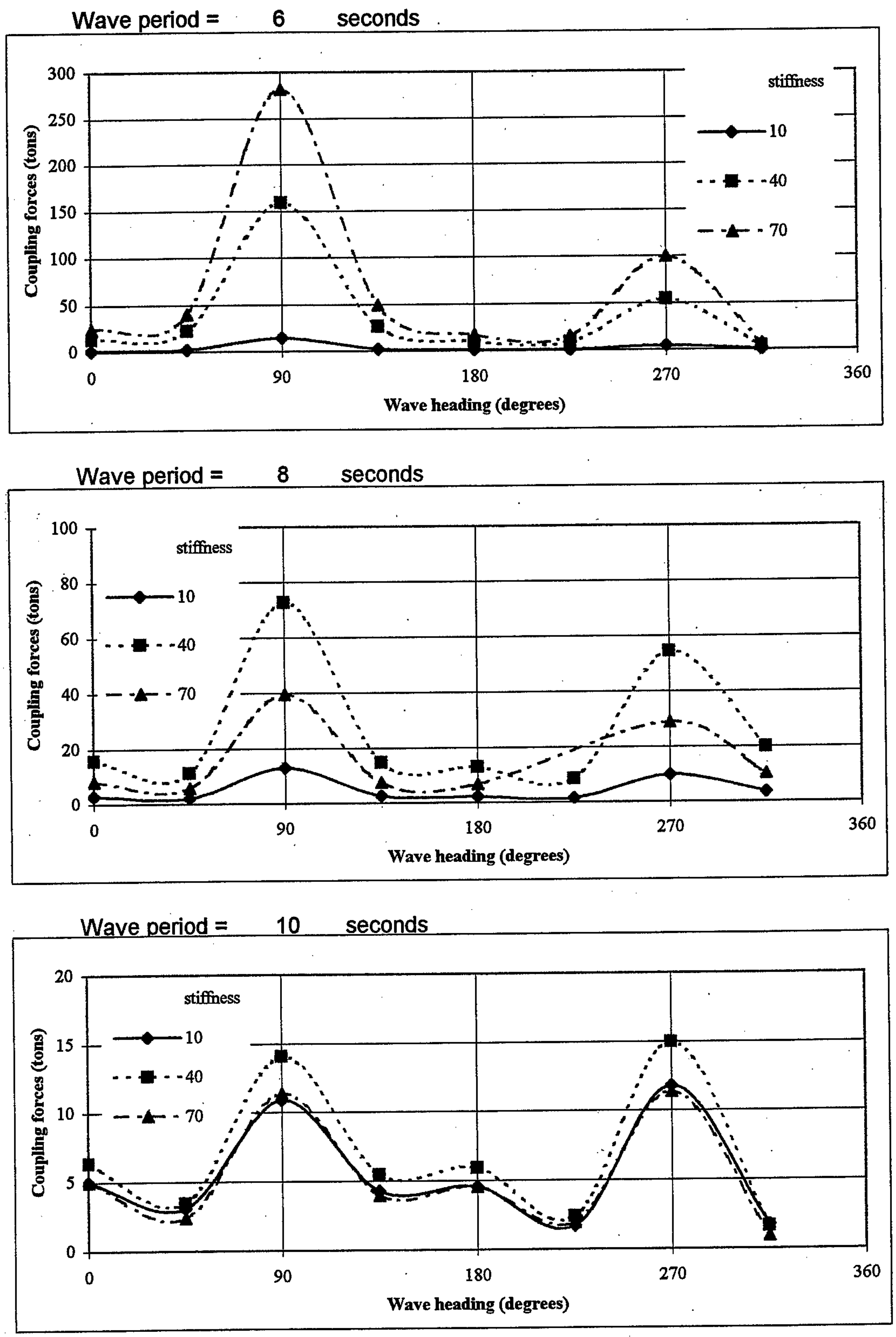


Figure 19. Coupling forces versus wave heading.

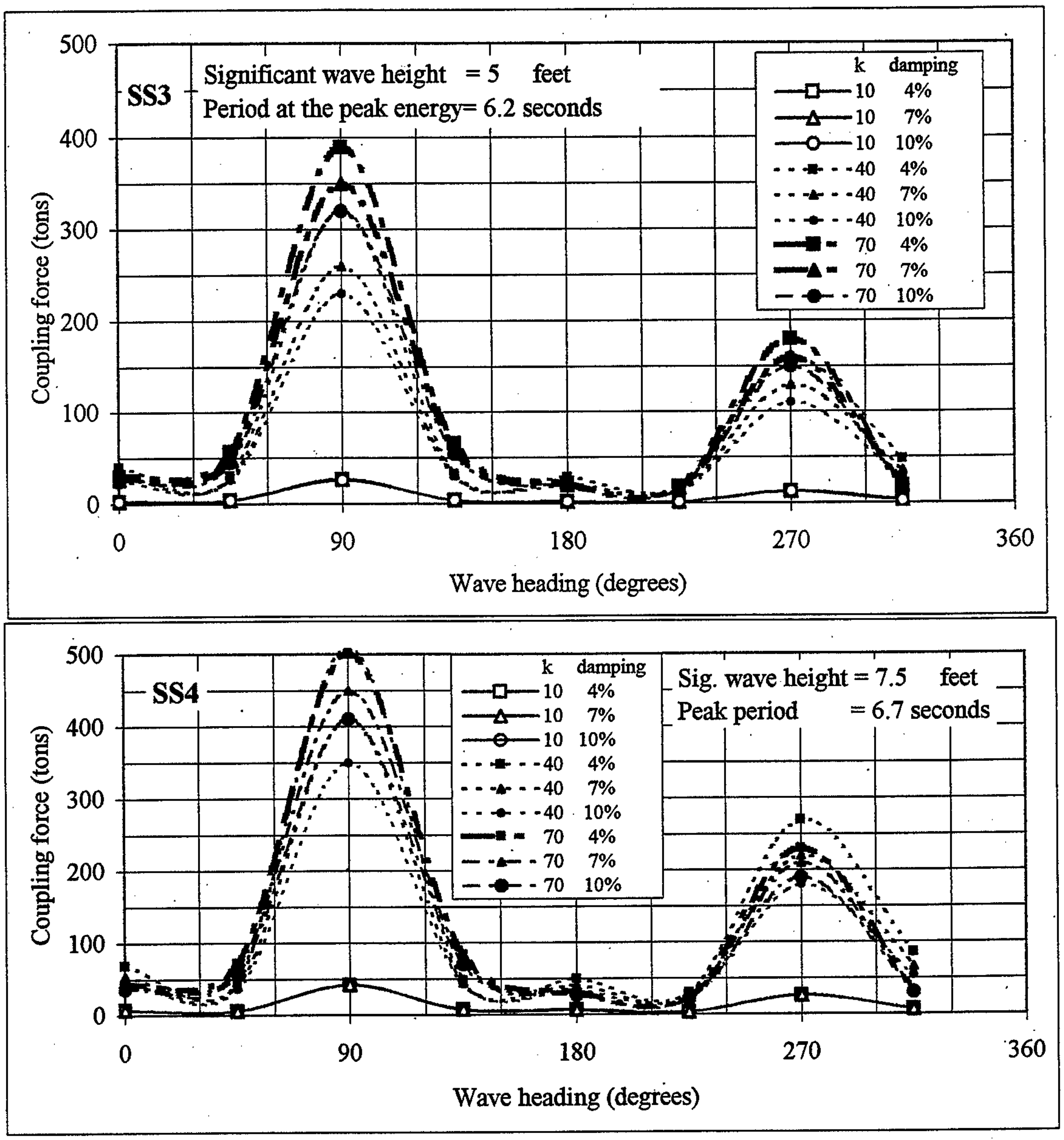


Figure 20. Coupling forces in random seaways ss3 and ss4.

Appendix A

SOFTWARE PROGRAM COSDYN

TYPICAL USAGE

COSDYN performs motion response analysis in time domain or in frequency domain for a compound floating structure with its connection system under the ocean environments.

PROGRAM DESCRIPTION

The compound floating structure consists of either single body or multiple bodies with connectors between each body. The floating structure can be moored in the open water, at a pier, at a near shore platform, or at a sealift ship.

COSDYN computes floating body motion responses, associated connector reactions, and mooring line tensions to regular waves or random waves in frequency domain; to irregular waves, wind, and current conditions in time domain. The program treats each body in six degrees of motion freedom, and includes connector force, nonlinear and asymmetric mooring forces, and moments introduced by an arbitrary catenary mooring and fender system. The effects of coupled motions between each body and the hydrodynamic interactions between bodies are taken into account in the numerical simulation of COSDYN

In the analysis, the body motions and associated mooring line tensions, connector reactions, and fender reactions are calculated step by step by the time domain Newmark integration method, in which all the important non-linearity terms are preserved. In the frequency domain, the nonlinear terms are all linearized. Frequency domain approach is very effective for the parametric study.

CAPABILITIES

The program COSDYN can be applied to a wide range of floating vessel motion applications, such as:

- Dynamic analysis of a moored vessel at a pier, at a near shore sealift ship, or at open sea
- Simulation of berthing maneuvering
- Analysis of relative motions between multiple vessels and their connector forces between vessels
- Simulation of the rigging process for an ocean barge module during installation
- Dynamic analysis of a floating pier in a heavy seaway